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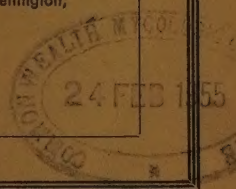

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(AGRICULTURAL RESEARCH SECTION)

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NOTICES

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BLOAT IN CATTLE ON RED CLOVER. I.

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(Received for publication, 2 September 1954)

Summary

Bloat was studied in five dry cows (2 pairs of identical twins and a single cow) fed in stalls on cut red clover. Within wide limits the production of bloat was not conditioned by rate of intake or total intake of dry matter (D. M.). The tendency to bloat appears to be an inherited characteristic. There were similarities between twins and differences between pairs in bloating behaviour, reaction to different periods of starvation, and reaction to change in D. M. content of the clover.

Bloat was produced at all stages of wilting of clover up to hay of 72% D. M. content.

Neither rumen movement nor the eructation mechanism were inhibited during the onset of bloat.

The cause of the ailment appeared to be foaming of the rumen contents. Anti-foaming agents were the only reliable preventive method or treatment for the condition. Adrenalin and an antihistaminic were definitely dangerous. During the trial period 429 cases of bloat of varying grades of severity were produced.

INTRODUCTION

Bloat is a disorder of ruminants which occurs in all parts of the world where grazing of legumes is an established practice. It is characterized by an interference with the normal elimination of gas produced by microbial digestion of the food in the rumen. Gas accumulates, the extended organ exerts pressure on the diaphragm and contiguous blood vessels, and when this pressure becomes excessive the animal dies. Bloat has been occasionally reported as occurring in cattle grazing lush young grass, green cereals, turnips, or chou moellier, but in the main it is considered to be caused by the ingestion of legumes. The grassland economy of New Zealand depends primarily on clovers which are virtually the sole source of nitrogen in high-production pastures and which are therefore an essential, and at certain times the dominant, element in the association. It has been claimed that the incidence of bloat has been steadily increasing in recent years, concurrently with the introduction of more vigorous clover strains. The validity of this claim

is difficult to substantiate or refute, but it is certain that bloat is not a recent phenomenon. A description of the ailment written in 60 A.D. is available (cited by Tribe, 1947).

In some areas of New Zealand, bloat is a problem causing serious inconvenience to dairy farmers almost every year. The loss of up to six animals from one herd in a single day has been reported during the 1953–54 dairy season. Perhaps as serious as the loss of valuable animals are the indirect losses. Bloat reduces milk production, causes farmers to hesitate to use clovers in their pastures, and makes necessary the constant supervision of the herd. Bloat in sheep is only rarely encountered in New Zealand.

The widespread occurrence and serious nature of bloat have stimulated research in many parts of the world. However, as Dougherty (1953) has stated, "General interest has exceeded carefully controlled experimental work on bloat. Experimentation has been somewhat sporadic and individualistic in character kept alive by comparatively few people working on their own initiative." The reason for the sudden failure of the gas elimination process has been the subject of many theories and researches which are described in the excellent reviews of Cole *et al.* (1945) and Dougherty (1953).

Little work has been done on bloated animals kept under controlled conditions of feeding and treatment, as the sporadic nature of its occurrence and the differing degree of susceptibility of individual animals have made it difficult to produce at will. The present work was commenced with the object of studying bloat in dairy cattle under stall feeding conditions. Preliminary work was carried out in 1952 and 1953 to determine the best forage and conditions for producing the ailment (Newbold 1954). The methods used are the result of this survey. This paper deals with the general results of bloat-feeding experiments carried out in the summer and autumn of 1954. A further paper deals with the quantitative aspects of various preventive treatments.

METHODS

Animals

Five dry dairy cows (2 pairs of identical twins and a single cow) known to be prone to bloat were used throughout the experiments.

Twin numbers were (1) 293 and 294 (2) 127 and 128, and the single cow 262.*

Food

Trifolium pratense (cowgrass or broad red clover) grown in pure stand was cut and fed to the animals in stalls.

Four different areas of red clover were employed:

(a) Red clover sown 15 months previously in plots cut twice in the spring of 1953 and fed in January 1954 as the second regrowth.

(b) and (c) Areas sown 10 months previously in the autumn of 1953 and cut during the late spring. The first and second regrowths were fed during the experimental period.

*One of a pair; the other twin died as a result of drenching.

The soil of areas (a), (b), and (c) is described as a light river silt.

(d) An area on heavy clay was sown in the autumn of 1953, cut in the spring and a hay crop taken in December 1953. The second and third regrowths were used.

Samples of clover were taken at each feed for dry matter determinations.

Feeding Regime

Food was withheld from the animals overnight and two feeds to full appetite were given, one at 8.30 a.m. and the other 1.30 p.m. The animals were in the stalls for approximately 2 h. at each feed giving a break of $2\frac{1}{2}$ to 3 h. between morning and afternoon feeds with a gap of 16 to 17 h. from afternoon until next morning feed. The cows were on a bare field when not being fed, with free access to water. Water was not available during the stall-feeding period. Feeding continued for 7 days a week over some periods, while during others the cows were turned out on a pasture of ryegrass and white clover during Saturday and Sunday. The feeding boxes were designed so that the amount of clover present could be weighed at any time without interrupting a cow's eating for more than 15 sec. When rate of intake was being measured, weighings were made at 10 min. intervals. Weights were recorded to nearest 0.1 lb. and rates of ingestion have been calculated for the first 30 min. of feeding.

Measurement of Relative Degree of Bloat

The severity of bloat was judged by eye and palpation of the left flank. The following is the definition of degree of bloat employed:

Grade I Mild bloat, left flank well filled out, soft to hand pressure.

II Moderate bloat, flank more distended than in I, fairly soft to hand pressure.

III Medium to severe bloat, both flanks distended and firm.

IV Severe bloat, animal obviously distressed and in need of treatment.

RESULTS

The period under review was from 12 January until 6 May 1954. During this period 429 cases of bloat were observed in the five animals. The bloat occured chiefly in two periods (1) 18 January to 22 February when moderate bloat occurred, followed by a 3 weeks' period of no bloat, and (2) a period of considerably more severe bloat from 17 March until the end of the experimental period. The following observations on the pathogenesis and treatment of clover bloat are described:

1. Weather conditions.
2. Stage of growth of clover.
3. Relation between dry-matter content of clover and severity of bloat.

4. Prefeeding as a method of bloat control.
5. Influence of rate of feeding.
6. Rumen movement and belching during bloat.
7. Bloat treatment by adrenalin and an antihistaminic.
8. Bloat treatment by drenching.
9. Foaming properties of rumen contents and clover juice.
10. The relationship between morning and afternoon feeding and bloating behaviour.
11. Twin efficiency as shown by similarity in bloating behaviour.
12. Twin efficiency as shown by intake.
13. Comparison of dry-matter intake to produce various degrees of bloat.
14. Relation between dry-matter content and total dry-matter intake.
15. Relation between dry-matter content and rate of dry-matter intake.

(1) *Weather Conditions*

It is frequently stated by farmers that weather conditions such as heavy dew, rain, wind, or humid cloudy conditions producing soft rank growth, are responsible for the development of bloating pastures. From our data there appears to be very little correlation between weather conditions and potency of red clover. The period October to November 1953 was characterized by above-average rainfall and mean temperature, but little bloat was produced on red clover that caused bloat so consistently when fed from the same areas to the same animals from January to May 1954.

The mean temperature and rainfall of the period September 1953 to May 1954 are shown in Table 1.

TABLE 1. WEATHER RECORDS FROM SEPTEMBER 1953 TO MAY 1954

Month	Rainfall (in.)	Rainfall 19 year Average	Mean* Temperature	Mean Temp. 19 year Average
1953				
September	3.69	2.79	51.6	50.5
October	5.42	3.95	54.3	54.1
November	3.35	3.25	59.8	57.2
December	3.58	5.71	62.5	60.8
1954				
January	1.52	3.42	62.5	62.0
February	0.91	3.34	66.4	62.4
March	3.89	2.62	63.8	60.6
April	1.28	3.09	55.9	56.1
May	1.53	3.29	53.3	51.0

*Mean Temperature = $\frac{1}{2}$ (Max. + Min.)

The January rainfall consisted largely of 0.43 in. on the 6th and 0.94 in. on the 10th. Only 1.43 in. fell between 10 January and the end of February, most of which fell in scattered showers of not more than 0.20 in. These can have had little beneficial effect on soil moisture as they were almost invariably followed by drying winds and warm days.

When stall feeding commenced on 12 January, rain had fallen two days earlier. No bloat was experienced during the first six days though red clover ranging in D. M. from 13.7% to 18.3% from two different areas was tried. Bloat was recorded on 18 January for the first time. This was eight days after the last rain and the weather over the period which led up to the development of potent clover is shown in Table 2. The weather records were observed at 9 a.m. on the date given and so refer (except for relative humidity) to the previous 24 h.

TABLE 2. WEATHER RECORDS FROM 12 TO 20 JANUARY AND GRADE OF BLOAT

Date	No. Bloated Cows	Grade of Bloat	Relative Humidity	Maximum Temperature	Hours of Sunshine
Jan. 12	—	—	61	65.2	12.0
13	—	—	73	68.0	10.3
14	—	—	74	65.8	1.2
15	—	—	73	64.8	2.4
16	—	—	51	68.5	12.8
17	—	—	57	77.8	13.0
18	4 3 2	III II I	54	77.2	13.0
19	1	II	65	80.4	11.9
20	4 2	III II	73	76.5	11.4

It will be noted that the days on which bloat occurred are characterized by low relative humidity (compared with Tables 3 and 4), long hours of sunshine, and high maximum temperatures. It might be postulated that bloat did not occur during the first six days of feeding in January because the animals had to become sensitized or the rumen flora adapted to the pure red clover. There were, however, a number of occasions during the trial period when animals were not fed on red clover for periods ranging from 1 to 4 days. Severe bloat was often encountered the first time red clover was fed again after the break in feeding routine. Bloat continued to be prevalent until 24 February but decreased in frequency and severity, particularly with cows 127 and 128, between 12 and 24 February.

The weather over the period leading up to the date when bloat ceased is recorded in Table 3.

TABLE 3. WEATHER RECORDS FROM 20 FEBRUARY TO 3 MARCH WHEN BLOATING PROPERTIES OF RED CLOVER DIMINISHED

Date	Grade of Bloat	Relative Humidity	Maximum Temperature	Rain	Hours of Sunshine
Feb. 20	Not fed	83	75.8		0.1
21	Not fed	74	73.2		10.3
22	4 cows III 3 „ II	73	76.8		7.8
23	2 cows I	56	78.8		11.8
24	Nil	67	78.8		7.6
25	Nil	80	77.9		3.1
26	Nil	98	82.6		8.7
27	Not fed	62	78.5	0.06	3.0
28	Not fed	88	66.3	0.05	2.4
March 1	1 cow II	98	79.9	0.15	2.1
2	Nil	75	76.5	0.03	6.1

It will be seen that relative humidities were higher, and the hours of sunshine less, during the period covered by Table 3 than that in January when potency of the clover was increasing. Bloat did not occur again until 15 March. Clover from various areas at different stages of growth and ranging in D. M. from 12% to 25% were fed during this interval without success.

TABLE 4. WEATHER RECORDS AND BLOAT FROM 8 TO 17 MARCH

Date	Grade of Bloat	Relative Humidity	Maximum Temperature	Rain (in.)	Hours of Sunshine
March 8	Nil	72	71.8	1.15	0.7
9	Nil	78	67.8	0.28	2.7
10	2 Grade I	80	71.5	Tr	2.2
11	1 Grade I	84	72.8	„	1.3
12	Nil	93	77.0	„	5.8
13	Nil	94	78.0	„	7.2
14	Not fed	79	79.0	0.29	8.9
15	3 Grade I	96	66.1	0.14	4.3
16	1 Grade IV 5 „ III 1 „ II	75	70.4	—	9.6
17	1 Grade IV 2 „ III 2 „ II	78	72.0	—	0.4

On 15 March slight bloat appeared in the afternoon and on the 16th the most severe bloat encountered up to that time was experienced. This was 8 days after 1.43 in. of rain had fallen on 8 and 9 March followed by 0.29 in. and 0.14 in. on 14 and 15 March.

The weather after the rain is given in Table 4.

There was less sunshine and higher humidity in this bloat-development period than was the case in January (Table 1). It appears that the only feature in common is that bloat developed 8 to 9 days after heavy rain in each case. Soil moisture must have been lowered con-

TABLE 5. NUMBER OF TIMES COWS BLOATED IN 4 PERIODS, AND SEVERITY OF BLOAT

(Points in right hand column calculated by multiplying severity of bloat by number of cases)

Period	Cow No.	No. Times Fed	Bloat				No. Treated to Prevent Bloat	Points
			I	II	III	IV		
1. 12 Jan. to 10 Feb.	293	49	5	7	21	—	—	82
	294	49	3	4	27	—	2	92
	127	49	3	1	12	—	—	41
	128	49	1	7	15	—	—	60
	262	49	4	17	13	—	1	77
	Total		16	36	88	—		
2. 11 Feb. to 10 Mar.	293	34	6	2	2	—	—	16
	294	34	2	2	10	—	—	36
	127	33	1	1	—	—	—	3
	128	33	1	2	3	—	—	14
	262	34	3	8	5	—	—	34
	Total		11	15	20	—		
3. 11 Mar. to 7 Apr.	293	48	4	7	14	7	2	88
	294	48	6	5	14	6	3	82
	127	48	5	8	6	5	—	59
	128	48	2	2	12	6	—	66
	262	48	6	9	7	5	—	65
	Total		23	31	53	29		
4. 8 Apr. to 6 May	293	41	1	9	11	4	6	68
	294	39	2	4	12	5	7	68
	127	40	3	7	16	1	1	69
	128	41	1	1	9	7	1	58
	262	23	2	3	8	1	—	36
	Total		9	24	56	18		
	Total		59	106	217	47		
			Grand Total = 429					

siderably in late February and early March owing to the lower rainfall in February. However, soil moisture can hardly have been the limiting factor during the spring-feeding period or in early January. With higher rainfall in March, bloating continued fairly consistently through April until 6 May when experimental feeding stopped.

The severity and number of cases of bloat occurring at various stages in the feeding programme can be seen in Table 5.

The analysis of the feeding results for similarity in bloating behaviour within pairs of twins and the differences between pairs are dealt with in section 11. However, it will be seen from Table 5 that twins 293 and 294 were the most consistent bloaters with 262 next in line. The greater susceptibility of 294 compared with 293 was best seen in the 2nd period when a comparatively small number of cases occurred. It is of interest that, of the 429 cases produced, 264 or 62% were grade III or IV.

(2) *Stage of Growth of Clover*

Bloat is usually associated with young rapid growth of clover (McCandlish and O'Brien 1933). In our feeding experiments, bloat was experienced at all stages of growth up to mature plants in which seed had set. There appeared to be a greater tendency for severe bloat on clover of lower D. M. content and, as the analysis of data given in section 3 shows, higher D. M. content in general reduced the bloating severity in 127 and 128 but not in 262 and 294. However, there were several occasions on which Grade IV bloat was produced in cows 127 and 128 with clover in flower and D. M. content above 22%. On other occasions clover at the 6 to 9 in. stage and of 12% to 15% D. M. did not produce bloat when fed.

The evidence from these experiments is that when the conditions for producing bloat occurred, clover at all stages of growth produced bloat to some degree. Conversely, in the period from 24 February to 10 March, clover at all stages of growth was safe.

(3) *Relation between Dry Matter Content of Clover and Severity of Bloat*

Succulence of feed has been claimed to be a cause of bloat and it is often recommended that bloat-producing herbage should be cut and wilted to make it safe for cows (Cole *et al.* 1945).

In this section are presented the analyses of feeding experiments to determine (a) the relation between D. M. content and severity of bloat on clover between 12% and 25% D.M. and (b) the effect of increasing D. M. content by wilting.

(a) The linear regressions to show the effect of D. M. content on Grade of bloat are:

	D = D. M.%	B = Bloat Grade		
Cow *293*	B = 2.983 − 0.074D	F = 2.77 (*)†	(1,101)	d.f.
294	B = 1.634 − 0.010D	F = 0.04 —	(1,96)	d.f.
127	B = 2.650 − 0.099D	F = 6.47 *	(1,102)	d.f.
128	B = 3.393 − 0.118D	F = 7.12 **	(1,99)	d.f.
262	B = 2.627 − 0.032D	F = 0.62 —	(1,94)	d.f.

†Symbols used in tests of significance throughout the paper are:—

— Not significant
(*) Significant at 10% level
* " " 5% "
** " " 1% "
*** " " 0.1% "

It was found that the regressions do not differ significantly and the data for the five cows may be combined to give a general regression applying to the five cows. This general regression is:

All cows B = 2.629 – 0.066 D.

The test for significance of the regression for all cows is:

Source of Variation	d.f.	Mean Square	F	F required: 5% (1%)	Result
Regression	1	20,620	10.41	3.86 (6.70)	**
Residual	500	1,980			
Total	501				

Thus in the population represented there was a highly significant downward regression of bloat score with increasing D. M. content, the regression equation showing that an increase of D. M. of 10% is associated with a bloat decrease in mean bloat grade of 0.66. For cows 294 and 262 there was no significant effect of increasing D. M. content on bloat severity while with 293 the regression was significant only at the 10% level.

(b) On a number of days during the experimental period clover was cut and allowed to wilt in the field. On two occasions the wilting was taken to the hay stage. A summary of typical wilting experiments is given in Table 6.

In Experiment 1, 24 h. wilting was sufficient to eliminate the bloat-producing properties of the red clover. However, this material was cut on the first day that bloat appeared and probably was not particularly potent. Experiment 2 is a good illustration of the difficulties associated with bloat research. Cow 293 did not bloat on 7.20 lb. D. M. of the fresh clover but bloated to Grade III on 6.85 lb. of material wilted 48 h. which had increased in D. M. content from 16.8% to 36%. In Experiments 3 and 4, one cow from each pair was fed hay made from clover cut at a time when more consistent bloat was being experienced than in either of the first two experiments. In Experiment 4, cow 294 bloated at a relatively low D. M. intake and rate of intake when compared with 128 which was negative.

Unfortunately hay was fed only in the afternoon and, as shown in section 10, cows 293 and 294 bloated equally well morning or afternoon, whereas 128 had a much greater tendency to morning bloating. It was also found that there was some effect of increasing D. M. content on bloat with 128, but not with 294.

No wilting experiments were done in the later periods when more severe bloat was being experienced on fresh material.

(4) *Prefeeding as a Method of Bloat Control*

One of the methods advocated for control of bloat is feeding the cows with roughage before they graze dangerous pasture (Cole *et al.* 1945). It is also claimed that feeding of a concentrate ration in the milking shed reduces bloat incidence when the cows return to pasture.

TABLE 6. FEEDING EXPERIMENTS WITH FRESH AND WILTED RED CLOVER

Exp. No.	Cow No.	Type of Feed	% D.M.	D.M. Ingested in lb.		Rate of Ingestion for first 30 min. in lb./min.	Bloat		Remarks
				To * Bloat	Total		Severity	Time to appear in min.	
	262	Fresh	16.5	2.81	2.81	0.046	II	69	Clover cut 18/1/54
	293	„	16.5	2.97	4.44	0.083	III	67	First occasion on
	294	„	16.5	2.26	3.26	0.064	III	77	which animals
	127	„	16.5	3.78	3.78	0.066	II	66	bloated after 6
	128	„	16.5	4.74	4.74	0.079	III	68	days negative.
1									
	293	Wilted 5 h.	19.6	4.16	4.66	0.078	I	70	
	294	„ „	19.6	4.19	5.65	0.063	I	70	
	294	Wilted 24	29.2	—	9.96	0.165	—	—	Other 4 cows fed fresh clover, only 128 bloated II.
	262	Fresh	16.8	3.75	4.71	0.077	II	91	Cut 25/1/54. Cows
	293	„	„	—	7.20	0.101	—	—	bloated moderately
	294	„	„	4.50	6.18	0.085	II	91	both a.m. and p.m.
	127	„	„	3.95	6.60	0.097	III	91	for several days
	128	„	„	3.40	6.65	0.099	III	81	before and after this date.
	294	Wilted 20 h.	20.4	4.86	7.00	0.106	III	80	
2									
	262	Wilted 24 h.	26.2	6.55	9.09	0.131	III	84	
	293	Wilted 48 h.	36	4.43	6.85	0.147	III	55	p.m. feed.
	128	„ „	36	—	11.30	0.151	—	—	
	294	Wilted 96 h.	49.5	7.67	11.00	0.183	II	60	p.m. feed.
	128	„ „	49.5	—	9.41	0.178	—	—	
3	294	Red clover hay	77	4.23	9.40	0.15	III	48	Cut 4/2/54 Fed 8
	128	„ „ „	77	—	9.94	0.17	—	—	days later p.m.
4	294	Red clover hay	72	3.24	4.32	0.09	III	69	Cut 13/2/54 Fed
	128	„ „ „	72	—	8.93	0.14	—	—	6 days later p.m.

*This column gives the dry matter intake at which Grade I bloat appeared.

In a number of experiments the cows were fed with up to 2.0 lb. of hay (D. M. 84%) before being given red clover. The low amount of hay was used deliberately in order to provide roughage in such a quantity that it would not reduce intake of clover. No reduction in severity of bloat was obtained.

During January 1954, a concentrate ration was given on a number of occasions before feeding clover. This was a period of moderate bloat only, and irregular results were obtained with a prefeed of 3 to 5 lb. of concentrate. Control of bloat appeared to be obtained in some experi-

TABLE 7. EFFECT OF REDUCED RATE OF INTAKE ON BLOAT

Experiment A cows 262, 293 fed 5 min., food withheld 5 min.
„ B „ 128, 294 „ 5 „ „ „ 10 „
„ C cow 128, „ 10 „ „ „ 10 „

Exp.	Cow No.	Feed Treatment	D.M. %	D.M. ingested in lb.		Rate of ingestion for first 30 min. in lb./min.	Bloat Time in min.		Grade Bloat
				To bloat	Total		To appear	Final Severity	
A	262	Interrupted	16.3	3.90	5.24	0.068	60	90	II
	293	„	„	3.64	5.45	0.065	60	90	III
	127	Normal	„	3.82	6.75	0.120	32	65	III
	128	„	„	2.69	7.14	0.120	11	63	III
B	293	Normal	17.3	4.91	6.07	0.112	50	67	III
	294	Interrupted	„	4.77	4.77	0.052	85	100	III
	127	Normal	„	5.88	7.25	0.109	11	63	III
	128	Interrupted	„	4.53	5.70	0.057	85	99	III
C	293	Normal	14.3	3.30	5.35	0.089	47	71	III
	294	„	„	3.86	5.66	0.106	37	61	III
	127	„	„	4.19	7.03	0.101	43	72	III
	128	Interrupted	„	4.33	6.08	0.062	70	110	III

ments; in others the cows fed concentrates bloated whereas the controls did not. In this type of experiment one positive bloat with concentrates nullifies a great many negative results.

No feeding of hay or concentrates was carried out in the later stages of the feeding programme when more severe bloat was encountered. However, an experiment was carried out on the Massey College dairy farm in 1949 by Professor Riddet and Mr. Johnson. The herd of 44 Friesian and 64 Jersey cows was divided into two equal groups. In one group the Friesians were fed 10 lb. and the Jersey cows 8 lb. of concentrates per day at milking time, and were at pasture between milkings. The control group received only pasture. Both groups were watched during the day and evening for two weeks and all cases of bloat recorded.

	Friesians	*Jerseys*
Cases bloat. No concentrate	55	33
„ „ Concentrate	59	15

It is often believed that feeding animals before turning out to pasture will reduce appetite. With the amount of hay (2 lb.) and concentrates (3 to 5 lb.) given to the stall-fed animals it appeared that the reverse was the case. The highest intakes of red clover were recorded for cows that had the greatest quantity of hay or concentrates. Considerably higher amounts of prefeed would no doubt reduce appetite.

(5) *Influence of Rate of Feeding*

It is frequently stated that the rapid ingestion of succulent pasture is a predisposing factor in bloat production and that the greedy eaters are most prone to bloat (Phillipson, see Marston, 1951). To test this, experi-

ments were conducted in which the rate of intake of fresh clover was reduced by feeding for a period and then withholding the food. The results are given in Table 7.

In general, the reduced rate of intake considerably lengthened the time between start of feeding and the first appearance of bloat, but did not reduce its final severity. In the animals eating *ad. lib.* there was a wide variation in the time which elapsed between Grade I and the highest Grade reached. It would be expected that with a faster intake of digestible material resulting in more rapid gas production and a quicker increase in concentration of some factor causing gas retention in the rumen, more severe bloat would result. However, the relationship is obviously not a simple one.

The relationship between rate of intake of D. M. and severity of bloat was examined for all cows, for all days on which no treatment was applied and for feeds of dry-matter content as high as 36%. There was no significant relationship between rate of intake of dry matter and bloat grade. In the one case approaching significance the relationship (if any) was negative, that is, a high rate of intake was associated with a lower bloat grade.

The correlation coefficients between rate of intake of D. M. and bloat grade were:

293 — 0.117	*127* — 0.036	*262* — 0.040
294 + 0.055	*128* + 0.165	

As the degrees of freedom for all these coefficients are approximately 100, the values of r required for significance at the 5% level can be taken to be ± 0.195.

The relation between rate of intake of green clover and bloat grade was also analysed. None of the regression analyses for individual cows reached significance level (see also wilting experiments). There were no significant differences between the regressions and on combining them to give a general regression equation this was significant at the 10% level only.

(6) *Rumen Movements and Belching during Bloat*

It has been postulated that bloat is due to an inhibition of the belching mechanism either by a spasm of the cardiac sphincter, a lack of stimulus for the belching reflex, or by an inhibition of rumen movement (Cole *et al.* 1945).

It was noticeable that rumen movements became more marked in early stages of bloat. In fact, it was possible, after experience, to predict when the animals were likely to bloat by the appearance of rumen movements 10 to 15 min. after feeding commenced. Two severely bloated cows were punctured with hypodermic needle and it was obvious from the difficulty experienced in holding the needle in place that rumen movements were still very strong. These impressions were confirmed when records of the activity of the left flank were made by a technique described in Part II of this series. In the tracings, rumen movement was consistently found in Grade III and Grade IV bloat although it was not possible to assess quantitatively the efficiency of this activity.

TABLE 8. FREQUENCY OF BELCHING OF COW 294 WITH CLOVER OF DIFFERENT D.M.%

Cow No.	Food	D.M. %	D.M. intake up to start of timing	Bloat		No. of Belches	Remarks
				Beginning	End		
294	Fresh clover	24.6	6.1 lb. in 45 min.	—	—	16 in 16 min.	
„	Hay	72.0	4.8 lb. in 60 min.	—	—	8 in 9 min.	
„	Fresh clover	28.4	7.1 lb. in 70 min.	II	II	11 in 8 min.	
„	„ „	22.2	4.85 lb. in 90 min.	III	III	15 in 8 min.	Still III 15 min. after finish of timing

From observations on the many cases of bloat that were experienced, it was most noticeable that belching was not inhibited while the animals were becoming bloated. Up to Grade III, animals usually continued belching and did not always cease entirely in very severe bloat. The frequency of belching was often greater in a bloating animal than in the same animal when it was not bloating, as is shown in Table 8.

All cows were still eating when timing commenced. The cows eating hay and non-bloating clover averaged approximately 1 belch per minute, while the Grade III bloated animal averaged almost two per minute after a lower dry matter intake than on the other feeds. Belching right through to Grade IV bloat was frequently seen in Kymograph tracings to be given in Part II.

Lack of belching was not the cause of the animal's distension. The animal was obviously not getting rid of enough gas by its eructation mechanism even though the individual belches were often more audible than in a normal animal.

On occasions belching ceased in severely bloated animals but this appeared to be the effect of bloating rather than the cause.

(7) *Bloat Treatment by Adrenalin and an Antihistaminic*

The theory has been advanced by a number of workers that bloat is due to an allergic reaction mediated by histamine, or to paralysis caused by histamine or histamine-like substances in the rumen contents (see Dougherty 1953). Although there was no evidence of inhibition of rumen movements in any experiment, the treatment of bloated animals with adrenalin (Kerr and Lamont, 1946) and with mepyramine maleate (Carmichael, 1951) (Anthisan: May and Baker) was tried. The results are listed in Table 9.

It is obvious that both the adrenalin and Anthisan treatments were without effect in alleviating bloat. In fact, their use in several cases resulted in a condition more dangerous than before treatment and considerably worse bloat than in the control animals. The exception was Experiment 2 when bloat was not severe and when the control animal deflated more rapidly than that treated with adrenalin. The two animals which had to be drenched with antifoaming agents after Anthisan treatment appeared to deflate considerably more slowly than those treated by drenching without Anthisan treatment.

TABLE 9. TREATMENT WITH ADRENALIN AND "ANTHISAN"

(All injections given subcutaneously)

Exp.	Cow	Bloat	Treatment	Result
1	294	III	4 ml. 1/1000 adrenalin	Animal became worse after treatment IV bloat 45 min. later
2	293	III	5 ml. 1/1000 adrenalin	II bloat 30 min. later
	294	II	No treatment	I bloat 7 min. later
3*	262	III	20 ml. Anthisan 10.32 a.m.	11 a.m. IV bloat very serious—drenched "Avlinox"—II 11.45 a.m. (See Section 8)
	293	III	III 10.36 a.m. No treatment	No bloat 10.52 a.m.
	294	III	III 10.29 a.m. No treatment	II bloat 11.27 a.m.—did not go above III
	128	III	III 10.13 a.m. No treatment	No bloat 11 a.m.
4*	262	III	20 ml. Anthisan 10.36 a.m.	10.50–11.15 a.m. IV bloat.
	293	III	„ „ 10.25 „	10.40–11.15 a.m. IV bloat.
	294	IV	10.38 a.m. drenched 100 ml. of paraffin in 500 ml. water	11.05 a.m. no bloat.
5*	293	III	25 ml. Anthisan 10.25 am.	10.40 a.m. IV bloat. 10.46 very uncomfortable—drenched 50 ml. olive oil in 500 ml. water. 10.54 dangerously bloated—further 250 ml. oil given. 11.29 animal normal.

*Experiments 3, 4, and 5 carried out in conjunction with C. S. W. Reid.

It will be seen in Experiment 3 that three animals with Grade III bloat deflated naturally whereas the animal treated with Anthisan became dangerously bloated.

Animals 262 and 293 became worse after treatment with Anthisan in Experiment 4 whereas paraffin oil was very effective in relieving 294.

(8) *Bloat Treatment by Drenching*

Various types of drenches were employed for relieving animals of bloat. The only ones that were consistently successful were those that contained anti-foaming agents. Animals would often deflate in 30 min. without treatment, and a result was recorded as positive only if the control animals remained bloated for a period of 1 to 2 h. Drenching with anti-foaming agents before feeding was always successful in preventing bloat for that feed. A typical experiment is shown in Table 10 in which a ricinoleic acid derivative (Avlinox; I.C.I.) was employed both as a preventive and as a drench for relieving bloated animals.

The two animals 262 and 294 given Avlinox before feeding had the highest intakes and the flank appeared sunken throughout the experiments. Of the control animals, 293 and 128 were very severely bloated. Cow 127 was drenched when both 127 and 128 were Grade III bloat.

TABLE 10. TREATMENT WITH "AVLINOX" BEFORE AND AFTER FEEDING
(10 ml. in 500 ml. water)

Cow No.	D.M. ingested		D.M. %	Rate of ingestion for first 30 min. in lb./min.	Bloat	Time to Appear in min.	Treatment
	To bloat	Total					
262	—	6.80	16	.09	—	—	10 ml. Avinox before feeding
293	3.74	4.98	16	.10	I IV	37 82	No treatment
294	—	8.63	16	.11	—	—	10 ml. Avlinox before feeding
127	2.76	5.94	—	.10	I III	27 56	Drenched 10 ml. Avlinox at III—animal flat 19 min. after treatment.
128	3.78	6.09	—	.10	I IV	38 95	No treatment

Cow 127 deflated rapidly whilst 128 became worse and remained very severely bloated for a considerable period.

Drenching with a commercial silicone preparation completely relieved a bloated animal in 20 min., while its twin mate remained bloated. Similar results were obtained with turpentine and vegetable oils. These results will be treated in more detail in Part II of this series.

Drenching with commercial mixtures which did not contain anti-foaming agents or with water alone were ineffective.

(9) *Foaming Properties of Rumen Contents and Clover Juice*

As antifoaming agents were so effective in relieving and preventing bloat, an experiment was carried out to test the foaming properties of rumen contents. Two groups of sheep with rumen fistulae were fed *ad. lib.* on red clover and cocksfoot respectively. After seven days on these diets rumen samples were taken from each group. The rumen contents were filtered through muslin, centrifuged at 1,500 g. for 20 min. and the foam produced by shaking in a graduated cyclinder was tested for stability by letting stand at 37°c. The foam from sheep which had been fed red clover was stable for 12 h. and had decreased very little after 24 h. The foam from the grass-fed sheep completely disappeared in 90 to 120 sec.

Red clover and short-rotation ryegrass were frozen and thawed and the juice pressed out; 30 ml. of the juice of each were taken and shaken in graduated cyclinders. The foam on the grass juice disappeared completely in 1 h. while that on the red clover juice remained stable for 24 h.

An attempt to isolate a saponin from the red clover by the method of Jacobson (1919) was unsuccessful. At this stage a paper by Lindahl *et al.* (1954) appeared giving a method of preparation of a saponin from alfalfa. This method was tried and a small quantity of saponin with the property of forming a very stable foam in water was isolated from red

clover. The quantity of saponin present in clover has not been determined, but it appears that there are other foam-producing substances present.

A number of analyses of the feeding data are presented in the remaining sections.

(10) *Relationship between Morning and Afternoon Feeding and Bloating Behaviour*

As the animals were without food for approximately 16 to 18 h. overnight and only 2½ to 3 h. between morning and afternoon feeds, the feeding records were analysed for the relationship between bloating frequency and time of feeding.

The analyses were made for the days on which clover from the same area was fed both morning and afternoon and on which no treatments were given.

(1) *Cows 293 and 294*

There were no significant differences between the mean grades for a.m. and p.m. for either cow. The mean grades were:

293 a.m. 1.68 ± 0.21
p.m. 2.06 „ F = 1.60⁻(1,28) d.f.

294 a.m. 2.04 ± 0.21
p.m. 2.34 „ F = 1.05⁻(1,28) d.f.

When the data for 293 and 294 were combined, the apparent difference in favour of afternoon bloating still failed to reach significance level, the F found being 2.67 for (1,57) d.f.

(2) *Cows 127 and 128*

There were highly significant differences between the mean bloat grades for afternoon and morning for both cows. The mean grades were:

127 a.m. 1.32 ± 0.18
p.m. 0.32 „ F = 16.244** (1,28) d.f.

128 a.m. 2.20 ± 0.16
p.m. 0.44 „ F = 63.88** (1,28) d.f.

(3) *Cow 262*

There was a significant difference between morning and afternoon mean bloat grade in favour of morning bloating.

262 a.m. 2.30 ± 0.14
p.m. 1.72 „ F = 5.20* (1,26) d.f.

The differences between the pairs and the similarity within the pairs are most striking, and emphasize the danger of generalizing on animal reactions from a small number of animals.

(11) *Twin Efficiency as Shown by Similarity in Bloating Behaviour*

Identical twins were used in the trials on the assumption that their bloating behaviour would be more alike than that of two cows selected at random (Hancock, 1953b). The data for 41 days on which the animals were fed the same clover and on which bloat occurred, were examined by considering the daily bloat grades for the two pairs of twins.

Table 11 shows there were highly significant differences between the individual cows in susceptibility. These differences were in part due to a highly significant difference between the twin pairs but after allowing for this there remain highly significant differences between the members of any twin set.

TABLE 11. BLOATING BEHAVIOUR IN IDENTICAL TWINS

Source of Variation	d.f.	Mean Square	F	F required: 5% (1%)	Result
Days	40	2.743			
Cows	3	17.144	15.25	2.69 (3.94)	***
(Between Pairs	(1	40.006	35.59	3.92 (6.84)	***
(Within Pairs	(2	5.713	5.08	2.69 (3.94)	**
Residual	120	1.124			
Total	163				

Coefficient of Variation = 74.6 %

The components of variance in the above analysis allow an estimate to be made of the twin efficiency value. Using s_e^2, s_w^2 and s_b^2 to denote the residual, within pairs and between pairs variances respectively,

$$s_e^2 = 1.124$$

$$s_e^2 + 41\ s_w^2 = 5.713$$

$$s_e^2 + 41\ s_w^2 + 82\ s_b^2 = 40.006$$

whence twin efficiency value (Carter, see Hancock 1953a) is given by

$$E = \frac{s_b^2 + s_w^2}{s_w^2} = 4.7$$

That is, one pair of twins could be used to replace 9 ordinary cows in the bloat trials.

The estimate is based on two pairs of twins only and may be subject to very large errors. The difference between the twin pairs, providing the estimate of s_b^2, depends almost entirely on the two pairs chosen—the choice of two similar pairs would lead to an unnaturally low efficiency value and vice versa. From other data presented in section 10 the pairs appear to be fairly dissimilar in their bloating behaviour. It should be remembered that the pairs were picked because they were susceptible to bloat and are therefore not a random selection.

(12) *Twin Efficiency as Shown by Intake*

The food-intake data were examined for those days on which no differential treatments were applied and excluding all days on which any animal bloated. As shown in section 13, bloat has the effect of reducing dry-matter intake in some animals.

For dry-matter intake the components of variance were:

$s_e^2 = 0.634$

$s_w^2 = 0.014$

$s_b^2 = 0.012$

giving $E = 1.8$. This low value is a reflection of the similarity in intake of the two pairs chosen, and allows no estimate to be made of the relative efficiency of twins in studies of intake in general. It is interesting to note that if data from bloating days are included (as though intakes were recorded ignoring the occurrence of bloat) the value for E becomes 6.7. Hancock (1953a) found a twin efficiency figure of 9 for dry-matter intake on pasture using 12 sets of twins (E calculated by method of Carter).

(13) *Comparison of Dry-matter Intake of Herbage to Produce Various Degrees of Bloat*

One of the important effects of non-fatal bloat is the reduction in milk production resulting possibly from reduced intake of herbage. On the other hand, it is very frequently claimed that greedy eaters bloat readily, which implies a greater food intake by susceptible animals. In order to determine the effect of severity of bloat on intake, a comparison was made of dry-matter intake for all cows on all days on which one or more of the animals bloated. These data were classified by grade of bloat and analyses of variance used to compare mean intakes for each bloat grade for each cow, and for all cows together.

SUMMARY OF ANALYSES OF VARIANCE

Source of Variation	293		294		127		128		262	
	d.f.	Mean Sq.	d.f.	Mean Sq.	d.f.	Mean Sq.	d.f.	Mean Sq.	d.f.	Mean Sq.
Between bloat grades	4	12.2223**	4	9.051**	4	5.378*	4	16.317**	4	4.335 —
Residual	82	2.273	81	2.470	82	1.940	82	1.796	76	2.979

Thus, in the data for all cows except 262 there are significant differences between the mean dry intakes at different bloat severities. The mean dry intakes are plotted against degree of bloat in Fig. 1.

If the data for all cows is combined we obtain:

Source of Variation	d.f.	Mean Squares
Between bloat grades	4	53.271**
Residual	4.23	2.370

Thus there are highly significant differences between the mean intakes at different bloat scores when the means are taken over all cows. These means, their standard errors, and the successive detectable differences at the 5% level of probability are:

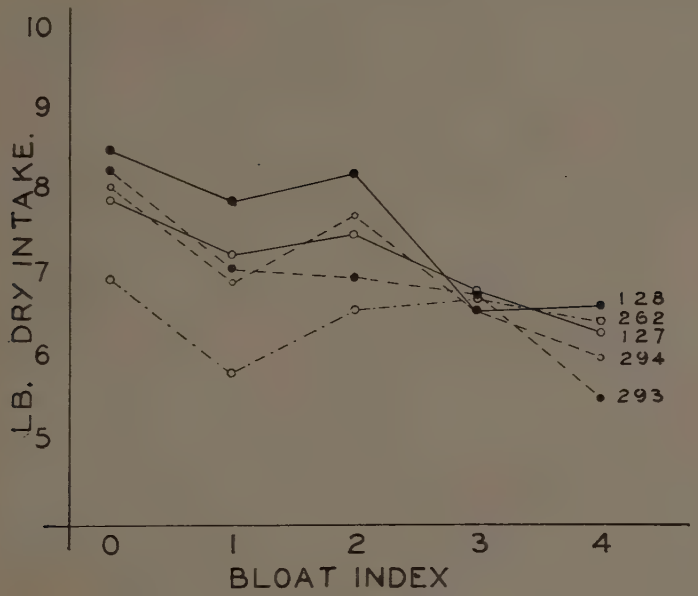

Fig. 1.—The mean dry matter intake for each cow at each bloat grade.

Bloat Grade	Mean and S.E.	d.05
0	8.10 ± 0.13	
		0.50
1	6.79 ± 0.22	
		0.56
2	7.17 ± 0.18	
		0.44
3	6.67 ± 0.13	
		0.60
4	5.94 ± 0.28	

Thus significant differences exist between the means 0–1, 2–3, 3–4, and the difference between 1–2 fails to reach significance level. However, if the data for cow 262 is excluded, the 1–2 difference is significant at the 10% level.

It is surprising that Grade I bloat reduced mean intake more than Grade II. With cow 262 bloat did not greatly affect dry-matter intake and this animal was observed to go on eating while becoming bloated. It appears that bloat definitely reduced dry-matter intake even if mild. Severe bloat is evidently not the result of a larger amount of fermentable material in the rumen.

(14) *Relation between Dry-matter Content and Total Dry-matter Intake*

It is generally believed that pasture growth in spring and autumn is too succulent to allow ruminants to obtain a maximum intake of dry matter. In the bloat trials, intakes of red clover at various D. M. contents

were recorded so it was considered to be of interest to examine the effect of dry-matter percentage on total D. M. intake.

The data were examined for each cow, for all days on which no treatments were applied and when no bloat was recorded, using all data in the D. M. content range of 12% to 36%.

To test whether D. M. intake is proportional to D. M. content or whether there is a departure from this relationship, linear regressions, and quadratic regressions of the form

$$I = a + b D + c D^2$$

where I = Total dry-matter intake (lb.)
D = Dry-matter percentage

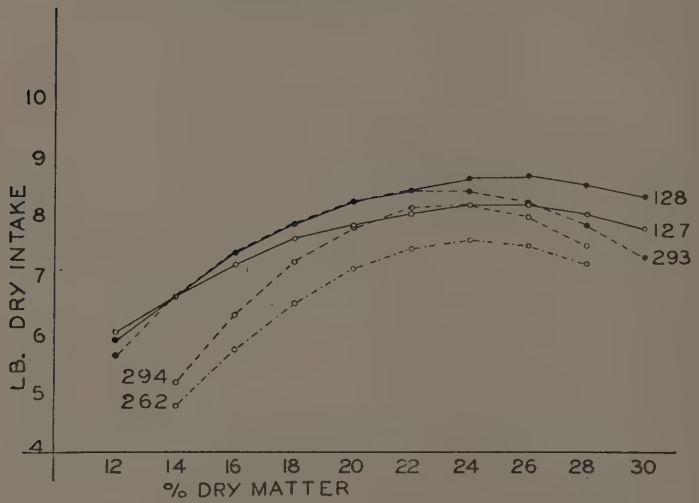

Fig. 2.—The mean dry matter intake for each cow at various dry matter contents.

were fitted to the data. The curves are plotted in Fig. 2. There were comparatively few points above 26% D. M. Hence the extent of the downward curving of the lines should be treated with caution.

The tests of significance of the linear and quadratic trends in the data are:

REGRESSION ANALYSES FOR ALL COWS

Source of Variation	293		294		127		128		262	
	d.f.	Mean Sq	d.f.	Mean Sq.	d.f.	Mean Sq.	d.f.	Mean Sq.	d.f.	Mean S.q
Linearity of regression	1	0.21—	1	0.39—	1	6.86(*)	1	6.68(*)	1	2.21—
Increment due to curvilinearity	1	15.14**	1	26.28**	1	7.07(*)	1	7.25(*)	1	14.62**
Residual	38	1.91	30	3.70	74	1.86	60	1.90	28	1.94
Total	40		32		76		62		30	

Thus for cows 293, 294, and 262 there were highly significant curves in the regressions of total dry-matter intake on dry-matter percentage, while for cows 127 and 128 there are curves in the regressions significant at the 6% level in both cases. That is, intakes were not proportional to D. M. percentage and the highest intakes were not achieved at the highest D. M. percentages.

The regression equations fitted $I = a + b D + c D^2$ allow estimates to be made of the D. M. percentages at which maximum intakes occurred; viz. D. M.% for maximum intake $= -\frac{b}{2c}$

These were as follows:

293	23%	*127*	25%	*262*	24%
294	24%	*128*	25%		

(15) *Relation between D. M. Content and Rate of D. M. Intake*

It might be considered that the slight decrease in intake above 25% could be attributed to palatability. However, the effect of D. M. percentage on rate of intake was examined for the two cows 293 and 128 as typical of the five, and the results were highly significant tests of linearity of regression (F 15.89 and 26.23 for (1,107) and (1,106) d.f. respectively) and almost significant tests of curvilinearity (F 3.41 and 3.65 respectively for the same d.f. as before). Thus rate of intake increased with D. M. percentage, but again the curves flattened at higher D. M. percentages.

The D. M. percentages at which maximum rates of intake occurred were calculated by the same procedure as in section 14 and gave 30% and 31% for cows 293 and 128 respectively. That is, the D. M. percentages at which maximum rates of intake occurred were rather higher than those for which maximum total intake occurred.

DISCUSSION

The results presented are for dry cows fed on red clover in stalls. The findings may not be transferable to the field, but this feeding regime was designed to produce bloat under controlled feeding conditions in order that the cause of bloat rather than the field control of the ailment could be investigated. However, there was nothing to indicate that the bloating behaviour reported above differed in any way from that occurring in the field.

Bloat in New Zealand is normally encountered in the spring (though it may extend well into the summer) and autumn. It is considerably more prevalent in certain districts than in others. White clover, which is subdominant in spring pastures, is incriminated more frequently than red, which gives its greatest production in the summer and autumn. Newbold (1954) has given the reasons for choosing red clover as the test material.

It appears from the results presented and from the literature that there are at least two major groups of factors in the etiology of bloat: a plant factor or factors usually associated with legumes, Cruciferae, and occasionally young ryegrass; and animal factors.

It is believed by the author that the independent variation of these factors is the main difficulty in research work on bloat. Some evidence on both these groups of variables has been obtained in the present study.

Environmental conditions appear to control the bloating potential of red clover. Theories as to the type of weather involved are many and varied, ranging from "wet weather", "clear dry weather", "dull humid weather", "dew" and "frost" (McCandlish and O'Brien, 1933: Cole *et al.* 1945) or "drought" (McIntosh 1937). None of these could be consistently blamed in the present series of experiments.

It seems probable that the type of weather that produces bloat on one species of clover may not do so on another. White clover in this area commences growth in the spring about a month earlier than red clover. On the other hand, owing to its deeper rooting system, red clover continues to thrive under conditions that are too dry for optimum growth of white clover. The weather preceding a particular period influences clover growth and presumably synthesis of a bloat-producing factor. If a cold wet period has been experienced, the best conditions for good growth are warm clear days. However, if a hot dry period has occurred, the best condition for growth is a period of reasonably cloudy weather following rain which allows the rain to penetrate the soil and be used by the plants without a high rate of transpiration. It is not implied that absolute rate of growth and bloating potency of clover are necessarily related, but the period during February and March when no bloat was experienced was one when clover growth was much reduced by lowered soil moisture. However, on the one occasion when irrigated pasture was fed during this period bloat did not result.

In our experiments bloat appeared in fine clear weather of relatively low humidity after excess rain (Table 2). It disappeared during days of high humidity with light showers overnight, relatively low sunshine, and high temperatures, but reduced soil moisture.

Bloat reappeared (Table 4) with increased soil moisture, high humidity, and moderate sunshine. Table 4 illustrates well how suddenly the pasture may change in its bloat-producing properties.

Henrici (1952) found in grazing experiments of lucerne in the Veld Reserve, Faunesmith, that not a single case of bloat resulted, whereas under similar meteorological conditions in another district, bloating was observed. Henrici states that a saponin was present in the lucerne from the bloat district and absent from that of the Veld Reserve, and believes that the difference may be due to a soil factor.

Both fertilizer treatment and soil deficiency have been claimed to induce bloat. Barrentine (see Marston 1954), presenting preliminary findings, believed that the results of his fertilizer trials indicated that very fertile soil or highly fertilized soil produces clover with a higher content of some bloat-producing substance than clovers on less fertile soils.

It appears likely that the climatic and soil factors necessary for the production of the maximum bloating potential in clover will be determined only when the substances present in the plant responsible for its occurrence can be estimated. It should not, however, be overlooked that the weather on a particular day may influence the animal reaction.

One of the puzzling features of bloat in dairy cattle is the variation among animals in their susceptibility to the ailment. There is little relationship between total intake of herbage by different animals and their bloat severity (Fig. 1, Grade IV) (see also Cole *et al.* 1942).

There is evidence that the tendency to bloat is an inherited characteristic. Knapp *et al.* (1943) carried out stall feeding with lucerne hay and concentrates to test the variation in occurrence of bloat in steer progeny of 13 beef bulls over two years. An analysis based on the number of bloat days showed a highly significant difference in both years between the progeny groups. Of the steers showing excessive bloat, approximately half were sired by one bull, and another third were traced to a common grandsire. Bloat was not found in all steers from any one of the sires though in 3 cases there was only one steer out of each lot that did not bloat.

Hancock (1953b), in grazing experiments with ten sets of identical twins, found that twin members of the same set showed a remarkable similarity in bloat incidence and that there were at the same time very great differences between sets. He noted that the level of production was not related to bloat incidence among the twin sets. One pair of the bad bloaters were high producers, whereas the worst pair for bloat were very poor producers. The situation was similar among the non-bloating sets. Hancock noted that 60% of the 20 cows selected as bad bloaters were the daughters of one bull, although the whole herd totalled only 30% of his progeny.

In the analysis of bloating behaviour in section 11 it was found that there was a greater difference between the pairs of twins than between members of either twin set. Similarities showed up in other analyses also. Perhaps the most striking difference between pairs and similarity within pairs is in relation to bloat at morning and afternoon feeding. It is widely held that the hungry animal is most prone to bloat and trouble will not be so serious if the animals can be kept full. The analysis of morning and afternoon bloating habits in section 10 show there was no significant difference for twins 293 and 294 between being without food for 2½ h. or 16 h. In direct contrast 127 and 128 showed a highly significant difference between morning and afternoon feeding in favour of morning bloat. Cow 262 was intermediate in behaviour between the two sets of twins giving a result in favour of morning bloat significant at the 5% level. It appears that the effect of starvation on bloat is an individual characteristic and illustrates how false results could be obtained if only animals of the type of either pair of twins were studied.

It seems likely that bloat does not result from the build up in concentration of any plant factor in the rumen as the result of several grazings of the pasture, otherwise more bloating would be expected in the afternoon.

There appears to be a great divergence of opinion in the literature as to the period during the day when most bloat occurs. McCandlish (1933) deduced from his survey of bloat in the Rhinns of Galloway that the evening is the most dangerous time. Barrentine (see Marston 1951) noted that more bloat occurred in the afternoon in animals that were turned out to graze in the morning. Cole *et al.* (1945) reported that bloat occurred as early as 28 min. and as late as 7 h. after the animals were turned out into pasture. In an experiment run at Massey College

Dairy Farm (Riddet and Johnson) in which cows were watched at pasture, the number of bloat cases were distributed as follows:

Morning (to 12 noon) 60; afternoon (12 to 3.30 p.m.) 23; evening 11.

It is obvious that the most severe bloat period of the day varies with the conditions and, as pointed out earlier, with the reaction of the cows concerned.

In an analysis of the D. M. content of clover over all feeds (without remedial treatment) there was a small reduction in bloat grade with increasing dry-matter content. However, in taking the cows individually, 294 and 262 showed no significant effect while 293 was significant only at the 10% level. Twins 127 and 128 were more affected in bloating by increasing dry matter. This is only the overall picture of bloat on clover between 12% and 25% D. M., and cases of Grade IV bloat did occur with this pair with clover of dry-matter content as high as 22.8%.

In section 14 the effect of the dry-matter percentage of the herbage on the dry-matter intake by the animal was examined. From an inspection of Fig. 2 it can be seen that twins 127 and 128 were similar with respect to intake except that the appetite of 127 decreased relative to 128 at the higher dry-matter percentages. By contrast the dry-matter intake of 293 was consistently higher than its twin 294, particularly at lower dry-matter percentages.

These results in Fig. 2 are for dry cows fed to appetite twice per day and may not give an accurate picture of the ability of milking cows at pasture to cope with succulent herbage. However, it may well be that some animals will produce more than others in a herd at low percentages of dry matter, whereas with more mature pasture there would be little between them.

Dodsworth and Campbell (1952) observed in feeding beef cattle with swedes and grass silage that the daily intake of dry matter appeared to be inversely proportional to the moisture in the feed. From feeding trials with sheep they considered that a dry-matter content of 20% to 25% was required for maximum performance of ruminants on succulent feeds, a figure that is in agreement with the present results. However, below 20% it may depend on the particular animal as to how well it copes with the increased moisture content.

From all these results on feed intake it is obvious that hereditary factors and individual animal behaviour must be taken into account in any complete examination of the etiology of bloat.

The results are discussed below in relation to current theories:

(1) *Excessive Consumption of Dense Feed*

This theory has been put forward by a number of investigators (see Cole *et al.*, 1944; Dougherty, 1953) who believed that the rapid ingestion of succulent foods causes a compact mass to form in the rumen and that this causes a physical obstruction of the cardiac orifice.

It has been demonstrated in our experiments that bloat is not a matter of speed of intake and that halving the rate did not decrease severity of bloat. Moreover, one of the most consistent bloaters, 262,

had the smallest appetite of all the animals (Fig. 2). Hancock (1953b) found that bloat is not limited to the high-production animals. Moreover, bloat has been obtained at all stages of growth and on hay, indicating that succulence is not a necessary attribute of the pasture for bloat production.

The continuance of belching while the animal distends, the striking control of bloat achieved by surface-active agents, and the lack of control achieved by feeding roughage are not explained by this theory. Moreover, bloat has been achieved by drenching with juice expressed from legumes (Ferguson, pers. comm.; Parsons *et al.*, 1952; Lindahl *et al.*, 1954; Newbold, 1954) when presumably no large food mass was present to cause mechanical blockage.

(2) *Physical Deficiency*

This theory was advanced by Cole *et al.* (1942) who claim that most bloat on green legumes results from the absence of roughage necessary to stimulate the functional reflex mechanism which they believe initiates belching.

The weight of evidence as presented in this paper is against the theory of lack of roughage. It appears that the eructation reflex is not inhibited: in fact, as shown in section 6, it seems to be more active in moderate bloat than in the normal animal. When belching ceases in a severely bloated animal it is probably the result of bloat and not the cause of it. Nichols (see Marston 1951) observed that belching did not cease as soon as symptoms of rumen distension became evident. Cole *et al.* (1945) quote the case of a cow, given 7 lb. of sudan hay just before pasturing, which still continued to bloat. They also state "At certain times when she was bloated, audible eructations occurred at the rate of five to seven per 5 minute interval, but she still remained bloated for an hour or more".

When the left flank of a moderately bloated animal was palpated to test the degree of bloat, it was observed that the action often resulted in a very audible eructation. This was also observed by Hancock (1953b). When the animals were more severely bloated this effect was not observed, as the flank was too highly distended to allow it to be depressed. Relief by simple pressure indicates that a stimulus by roughage is not necessary for the eructation action.

Weiss (1953b) concludes that the cardia is kept closed mostly through external pressure exerted by surrounding organs and by pressure on the abdominal portion of the oesophagus. The active dilation of the cardia is brought about by stimuli from pressure receptors in the rumen wall, the most sensitive of which are in the posterior dorsal blind sac. One cow was placed on a ration of young lucerne tops and this had no adverse effect on the efficiency of belching. Weiss believes that eructation is an independent reflex mechanism with pressure receptors in the rumen wall which are stimulated by gas pressure. Our results on the increased frequency of eructation in bloat agree with this theory.

There is ample evidence that roughage will not prevent bloat. In section 3 it was shown that bloat could be produced on red-clover hay though some animals appeared to be more affected by an increase in dry matter than others. The feeding of roughage before pasturing has been based on the opinion that:

(1) Roughage is necessary to initiate belching.

(2) Greedy eaters are most prone to bloat, and prefeeding will cut down the rate of intake.

Neither of these opinions appears to be backed by experimental evidence and both are contradicted in the results presented. Several investigators have reported that bloat occurs not only on legume hay but also is not prevented by prefeeding with hay when animals are subsequently pastured on dangerous pasture. It is pertinent to point out that, as bloat is characterized by such suddenness of onset and irregular incidence, the many cases of apparent control of bloat are negated by a few cases of breakdown of the treatment. This makes controlled experiments essential.

Cole (see Marston 1951) stated "It was necessary to feed 10 pounds of sudan hay to prevent bloat on alfalfa pasture. Barley straw was ineffective for this purpose as the animals would consume only 5 pounds. Alfalfa hay was of little or no value in preventing bloat when fed to animals grazing on alfalfa." This statement is most significant in that a large amount of roughage of a particular kind is necessary to prevent bloat; in fact an amount large enough to reduce appetite materially. Cole (see Marston 1951) states that cattle fed the top 3 in. of cut alfalfa bloated, but when fed the whole plant no difficulties were encountered. This has not been our experience. When red clover (15 to 18 in. high) was separated into stalks and leaves and fed separately to cows, as severe bloat was obtained in the animal eating stalks as in the one that consumed the leaves alone (Newbold 1954).

Colvard (see Marston 1951) found in a survey of 400 bloat cases, of which 121 resulted in death, that 140 cases of bloat occurred where hay had not been fed before turning cattle on to pasture and that 130 cases occurred where hay was fed before pasturing.

Grandstaff (see Marston 1954) reported that bloat developed in range ewes fed alfalfa hay in New Mexico. Smith (see Marston 1954) states that frothy bloat was observed when animals were fed alfalfa hay. Huffman (see Marston 1954) reported that hay alone was fed to one of a pair of identical twin calves and grain to another. The calf fed on hay was healthy while the calf on grain was sick but did not bloat. However, when hay was added to this calf's ration it bloated. The fact that alfalfa hay, even though eaten in a considerable amount, does not prevent bloat, rather it may produce it, indicates that a bloating principle present in the fresh alfalfa is preserved to some extent in the drying as was the case in our red-clover hay.

In the present work, definite differences have emerged between individual animals in their reaction to increasing dry matter in the feed and the non-recognition of this factor may have complicated previous observations.

Cole *et al.* (1945) stated that before the "physical deficiency" theory for bloat on green legumes can be accepted it should be proved that stimulation of nerve fibres in the oesophagus or rumen elicits the act of eructation, and that the addition of a chemically inert scabrous material to a bloat-provoking diet will prevent bloat.

They cite the fact that turpentine, an irritating material, will relieve bloat; however, the evidence indicates that the action of turpentine is due to its surface-active rather than to its irritating properties (Clark 1948, 1950). Not only has no conclusive evidence been put forward which fulfils Cole's conditions, but the evidence appears to be mostly to the contrary. However, the work of Cole and his colleagues has been most useful in clearing up some misconceptions and in stimulating research into this elusive ailment.

Clark and Weiss (1952) have recently demonstrated a salivary reflex in sheep and goats initiated by mechanical stimulation of the cardiac region of the rumen, and causing a four- to five-fold increase in saliva flow. When hay is fed more saliva is secreted, giving a watery consistency in which gas bubbles rise freely to the top to form a layer of unstable free froth. The occurrence of bloat on succulent lucerne is ascribed to the lack of coarse material with consequent diminution in reflex salivary secretion. The consistency of the ingesta is increased and if gas formation is adequate the ingesta swell to form a tenacious frothy mass.

This theory is open to the same criticism as that of Cole *et al.* (1945) in that a lack of roughage does not appear to be the cause of bloat. In the author's experience, sheep vary considerably in the consistency of their rumen contents on a hay diet. Some are watery while others are a solid mass of ingesta difficult to sample through a fistula. Moreover, bloat produced by drenching with clover juice is not explained by this theory (Newbold 1954).

The author believes that saliva may play a very important part in the pathogenesis of bloat, but its function is not explained by the lack of roughage theory. Weiss (1953a) appears to have overlooked the fact that saliva is itself a foam-producing liquid with a low surface tension (Reid and Huffman 1949).

Toxic Principle Theories

There are a number of theories based on the belief that bloat in legumes is due either to toxic substances ingested in the food or produced in the rumen. These all postulate that bloat results from an inhibition of the eructation mechanism by a paralysis of animal muscle. In none of the theories put forward has evidence been obtained from cases of natural bloat. Wester (1935) noted that there is hypermotility of the rumen in the early stages of acute bloat. Weiss (1953) found from clinical examination of animals with acute bloat that the rumen was in active movement. This was also noted in the present investigation. The better-known hypotheses will be dealt with briefly.

(a) *Hydrogen Cyanide:* Evans and Evans (1949) claimed that cyanide was an agent in the production of legume bloat. In our trials, red clover was chosen as it does not contain any appreciable amount of cyanogenetic glucoside. Evans and Evans found that sublethal doses of cyanide caused a cessation of rumen movements, but Clark and Quin (1945) found no inhibition of eructation in their experiments and concluded that there was no evidence for involving cyanide in the etiology of bloat in ruminants. It is certain that clover bloat can be produced without any cyanogenetic substances being present.

(b) *Flavones:* Ferguson *et. al.* (1949, 1950) isolated a smooth-muscle inhibiting substance from legume juice which they finally identified as tricin, 5, 7, 4′—trihydroxy—3′, 5′—dimethoxyflavone. He believed this may take part in the production of bloat. As there is no report of bloat having been obtained by feeding this substance the theory has little to support it.

(c) *Toxic Factors in Rumen Ingesta:* It has been claimed that the digestion of legumes in the rumen causes excessive production of toxic gases such as carbon monoxide or hydrogen sulphide which play a part in the pathogenesis of bloat. However, there appears to be no evidence that the concentration of these substances is any higher in bloated than in normal animals (Cole *et al.* 1945).

Dougherty and Cello (1949) found a toxic substance in the rumen of cattle and sheep which inhibited rumen motility in sheep. No evidence has yet been advanced that it is involved in the pathogenesis of bloat.

It does not appear from our feeding experiments that any marked toxicity was present. Bloating twice a day for many days on end did not reduce appetite or effect the appearance or vigour of the animals. They put on weight during the experimental period and appeared quite normal a short time after they had recovered from severe bloat. Further, when prefed oil before eating potent clover the animals ate hungrily without ill effects.

Excessive Gas Formation Theory

Before the microbial process of digestion in the rumen was properly understood this theory was widely accepted. However, the work of Cole *et al.* (1945) and Quin (1943) has indicated that in the normal animal no difficulty should be experienced in getting rid of all the gas that could be formed. In the present work it appeared quite definitely that belching continued up to the stage of acute bloat but that the cause of the trouble was retention of gas in the rumen mass rather than any difficulty in coping with the free gas.

As the amount of gas produced in the rumen is roughly proportional to the amount of herbage ingested and acute bloat occurs in animals with very different intakes, it does not appear that rate of production of gas alone offers an explanation for bloat production. In general, as seen in Fig. 1, the more severe the bloat the lower the intake.

Allergy Theory

This has been discussed in a separate paper by Johns and Reid (1954). Kerr and Lamont (1946) claimed success for adrenalin in the treatment of field cases of bloat on clover, green corn, and young green grass, while Carmichael (1951) states that "Certain cases of bloat or hoven have responded well to Anthisan especially those associated with a sudden change to a high protein diet such as clover". However, we found that treatment of bloat with adrenalin or an anthihistaminic is dangerous. This is in line with the findings of Dougherty (1942) that adrenalin causes marked depression in strength and frequency of ruminal contractions in cattle. Weiss (1953b) found that the intravenous injection of 1 cc. of adrenalin hydrochloride (1 : 1,000) into sheep caused varying degrees of depression and even total paralysis of rumino-

reticular activity. Eructation was inefficient during the period of ruminal immotility. While these treatments may be of use in other types of bloat they appear to be of little use in the disorder caused by clover ingestion.

Foaming Theory

Substances which reduce the surface tension of water tend to promote foam formation so that, if a fermentation takes place within the liquid, the gas produced may be retained within the froth formed. The proportion of the gas retained will depend on the stability of the foam.

All the evidence in the present work points towards the fact that the bloat was due to the physical retention of the gas within the rumen ingesta. The main points are:

(1) Anti-foaming agents never failed to protect animals from bloat or failed to relieve bloated animals.

(2) Eructation always took place when the animals were becoming bloated.

(3) No drench, whether irritant or not, was successful in relieving the ailment unless it possessed surface-active properties.

(4) Bloat was not relieved by the stomach tube. On one occasion clear rumen liquid was obtained without any food material, indicating that the tube had gone to bottom of the rumen and that the solids had all been carried to the top by foaming action. On another occasion only frothy ingesta was obtained and the tube blocked. It is presumed that bloat would be partially relieved if the tube were to reach the free gas space at the top of the rumen.

(5) When the rumen was punctured in acutely bloated animals a certain amount of free gas escaped. The needle then blocked with a frothy substance.

(6) In examining a cow that had just died of bloat it was found that the rumen was full of material that would not allow the release of pressure through a hole in the flank until a considerable amount of it was removed. The gas was held in a "solid foam", i.e., the foam was held by grass and clover stalks that gave it a strong supporting structure. It did not ooze out of an opening but was rather held in a rigid mass. The author believes that bloat is due to the retention of gas within the rumen ingesta by foaming of the rumen contents supported by the mass of plant material.

When an animal ingests bloat-producting pasture, gas is produced as a result of microbial fermentation, and the degree of bloat will depend on the relation between the rate of gas production per unit of time and the rate of its release from the rumen contents. It appears that there is always some release to give a pocket of gas at the top of the rumen, and eructation of this gas occurs while the animal is distending. However, if there is sufficient foaming agent present, release of gas will be much slower than gas production and severe bloat will result. Finally,

the high ruminal pressure will itself perhaps cause an interference with the process of gas elimination, either by so stretching the rumen muscles that sufficiently strong contractions to carry the gas bubble forward and downward to the cardia are not possible, or by some mechanism as suggested by Clark (1950) and Weiss (1953). The latter suggests that with a high intraruminal pressure, the anterior dorsal sac bulges over and presses on the cardiac orifice and abdominal portion of the oesophagus, thus causing a mechanical closure. However, severely bloated animals can still eat and a drench is always swallowed. Peristaltic movement down the oesophagus can evidently still carry material into the rumen against the pressure developed as a result of bloat.

It would be expected that if distension were simply the result of a balance between fermentation rate and the amount of foam-producing substance in the feed, the faster the animal ate the greater would be the fermentation rate and the quicker the release of foaming agent. Hence, the more severe would be the bloat. That this is not so is demonstrated by the analysis of feeding results in section 5. There appears to be little relationship between the rate of ingestion or total herbage eaten and bloat severity. It follows that there must be another factor involved. The most obvious one is the saliva secreted into the rumen. Reid and Huffman (1949) determined the surface tension of 55 saliva samples and found an average value of 47.1 dynes per cm. at 29°c with a range of 45.54 to 49.20. Pure water has a surface tension of 71.35 dynes per cm. at 30°c and as the saliva has a water content of 99.12% it must contain a potent surface-active agent. Sodium oleate, a standard surface-tension depressant, has a surface tension of 42.2 dynes per cm. in 1.1% concentration. The quantity of saliva (as suggested by Weiss 1953) and its surface tension may well be part of the animal factor.

Clarke (1950), in attempting to produce bloat artificially, passed 1 litre of gas per min. through a fistula into the rumen contents of six sheep that had been starved and then fed green lucerne. In the majority of the animals the gas was not retained and the sudden appearance of a "bloater" could not be explained. It was noted, however, that one particular animal reacted on several occasions. Burroughs (see Marston 1951) found that the surface tension of the ingesta of chronic bloaters was lower than that of non bloaters. However, it is known that it is not low surface tension *per se* that ensures foam stability, but the nature of the adsorbed layer giving rise to the lowering of the surface tension (Pankhurst, 1941). Pankhurst found that with most substances there is an optimum concentration to produce a stable foam. With naturally occurring substances, such as proteins and saponins, he found wide variations in foaming properties and surface tension depending on the source of the material. Moreover, small amounts of impurities could profoundly influence the foaming properties, particularly with respect to pH.

It appears to the author that the foam system in clover bloat will not be a simple one on account of the presence of at least three possible foam-producing systems: (1) saliva, (2) saponins (Lindahl *et al.* 1954), and (3) proteins and their breakdown products. It may well be that in young spring grass (1) and (3) are primarily involved.

The frothiness of ruminal ingesta has been incriminated by a number of workers as a factor in the etiology of bloat but few have claimed that it is the prime cause of the ailment. Cole *et al.* (1945), in

reviewing the work up to that time, did not appear to regard it as a major cause of the trouble. A number of people have postulated that saponins are involved and the references are given in the recent publication of Lindahl *et al.* (1954). Lindahl and co-workers appear to be the first to have produced bloat on a saponin isolated from pasture legume, even though no bloat was produced on the original material. The yield of saponin was about 0.5% of the dry weight of alfalfa. The dose rates to produce bloat appeared to be high and it is of interest to note that better bloat production was achieved when saponin, clover, or alfalfa juice was given to animals grazing legumes, rather than grass. Lindahl *et al.* (1954) state that distension appeared to be due to gas retention rather than froth since the passage of a stomach tube into the rumen permitted an immediate release of gas and a reduction of distension.

We have not been able to relieve natural clover bloat with the stomach tube but success or failure will depend on where the stomach tube goes in the rumen. Free gas has been shown to be present in the dorsal sac by puncturing the left flank but unless the stomach tube taps this pocket of gas no relief will be obtained. Smith (see Marston 1954) was also unable to relieve frothy bloat with the stomach tube. Clark (1950) treated natural cases of bloat by injecting antifoaming agents directly into the rumen with excellent results. In the few cases where belching did not occur spontaneously the gas was easily removed by stomach tube. It appeared that a very high intraruminal pressure interfered mechanically with eructation. Cole *et al.* (1945), in criticism of the foam theory, state that they have tapped a number of cows bloated on alfalfa pasture without encountering a single case where there was no free gas. The present author has had the same experience and agrees with Weiss (1953) that frothing is probably a matter of degree. It seems likely that the foam is never so stable as to retain all gas and that there will be a slow release to a gas pocket even in the most severe cases. The more stable the foam the smaller will be the amount of gas released and the smaller the amount eliminated by eructation.

Clark (1948 and 1950) has shown that turpentine—probably one of the most universally used substances in the treatment of bloat—exerts its effect by increasing surface tension and hence reducing foaming. Quinn *et al.* (1949) were very successful in the treatment of bloat with an agent that increases surface tension—a preparation containing a highly polymerized methyl silicone. Smith (see Marston 1954) found that methyl silicone was successful in treating frothy bloat and in preventing if for several days.

In our experiments all surface-active agents tried have been successful in relieving bloat and preventing it, e.g. "Avlinox", paraffin, silicones, peanut oil, olive oil, soyabean oil, and turpentine.

The evidence is very strong that the bloat reported in this paper was frothy bloat. The agents producing the foam may well be both saponins and plant protein and their hydrolysis products, while the contribution of the saliva with its variation in surface activity and volume, may be all or part of the genetically controlled animal factor.

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GOITROGENIC ACTIVITY IN LINSEED

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Summary

Congenital goitre has been produced in lambs under controlled conditions with diets containing linseed meal. In both mice and sheep it has been shown that linseed meal has a goitrogenic effect, which can be prevented by addition of iodide. The factor concerned is probably the cyanogenetic glucoside, linamarin.

Introduction

In 1951 Hart and Coop (pers. comm.) at this College observed that a diet composed of three parts of lucerne hay, one part of oats, and one part of linseed meal was goitrogenic. From a group of fourteen ewes fed this ration during pregnancy, eight ewes produced lambs with very large goitres. As each of the three feeds comprising the diet was drawn from a different locality it was considered that a straightforward iodine deficiency was unlikely and that a goitrogen was probably present in one or more of the dietary components. Of the three, the linseed meal was under suspicion most, on account of its hydrocyanic acid content. The work to be described below concerns the investigation of goitrogens in the diet and particularly in linseed meal.

It was shown by Coop and Blakley (1949) that the ruminal microflora of the sheep is capable of hydrolysing cyanogenetic glucosides, including linamarin, the glucoside found in linseed, with the release of free hydrocyanic acid. It was later found (Blakley and Coop, 1949) that sheep detoxicated cyanide by conversion to thiocyanate. Linseed might therefore display goitrogenic potency in sheep through the medium of thiocyanate. The goitrogenic action of this substance can be prevented by the administration of iodide (Wood and Edwards, 1949) whereas the factor responsible for the development of thyroid hyperplasia in rats fed on Brassica seeds has been shown to be insensitive to iodide (Kennedy and Purves, 1941). The response of the goitrous subject to supplementary iodine was therefore important.

Experimental Methods and Results

The linseed meal used throughout the work was a commercial product manufactured by crushing the seed and heating it in a steam-jacketed container. Steam was added in quantities dependent upon the original moisture of the particular seed, and the heated seed was put under pressure in a screw expeller, in order to remove the oil. The finished product had a moisture content of approximately 10%. On a dry-weight basis it contained 8.0% ether extract, 34.5% crude protein, and 0.0097% HCN $\pm$ 0.0005.

Two series of experiments were performed, the first with mice and the second with sheep.

*This project was undertaken at Canterbury Agricultural College during the tenure by the author of a National Research Scholarship awarded by the Department of Scientific and Industrial Research, New Zealand. The present address of the author is: Department of Urology, The University, Leeds, 2, England.

Experiments with Mice

Three groups were selected with approximately nine mice per group. Each group was allocated a different ration in order to observe the effects of these on the histology of the thyroid. The diets of the three groups were as follows:—

Group	*Diet*
1	100% control ration and drinking water
2	50% control ration: 50% linseed meal and drinking water
3	50% control ration: 50% linseed meal and aqueous potassium iodide (0.224 g./litre) in place of the drinking water.

The composition of the control ration was:

48.3% wheatmeal	11.6% meat meal
9.7% wheat germ	13.5% dried full-cream milk
7.7% yeast	1.9% dried blood
5.8% bran	1.0% calcium carbonate
0.5% salt (iodide-free).	

The cyanide content of this control ration was zero. Its percentage iodine content was 0.0038 ± 0.0003.

The cyanide content of the diet fed to Group 2 was 0.0042% HCN ± 0.0003 determined by the method of Gettler and Goldbaum (1947). Its percentage iodine content was 0.0026 ± 0.0003. Linseed meal itself contained 0.0013% iodine.

It was found that the average weight eaten per mouse per day was 5 g. accompanied by 5 ml. of water.

The working hypothesis adopted was that if linseed were goitrogenic it exerted its effect through the agency of thiocyanate, derived from linamarin. Since the accumulation of iodide by the thyroid is dependent upon the concentration of thiocyanate present, the daily intake of supplementary aqueous iodide was arranged to be equivalent to the cyanide intake from the linseed part of the diet. The concentration of such a compensatory iodide solution was found to contain 0.224 g. potassium iodide per litre. The mice of Group 3 were kept on the diet shown above for six weeks immediately prior to their death, and for another three weeks before this period on the same solid diet but with the use of only half strength potassium iodide solution, i.e., 0.112 g./litre, as the drinking water. Groups 1 and 2 were both fed their diets for a minimum of eight weeks before death and histological examination of their thyroids. The effects produced by Groups 1 and 3 should therefore be similar to one another but different from the expected effect shown by Group 2. This was found to be so.

It was noticed that a diet which contained more than 50% linseed meal produced a high mortality rate amongst those mice to which it was administered. This may have been due to the limited ability of the mouse liver to detoxicate cyanide.

Results of the Histological Examination of Mouse Thyroid Tissue

Group 1: The epithelium surrounding each lumen consisted of low cuboidal cells, typical of a normally active follicle. These follicles

were rich in colloid and the nuclei of the epithelial cells stained darkly.

Group 2: Signs of hyper-activity were very noticeable. The epithelium had become columnar and folded whilst the lumina contained only small amounts of dilute colloid. This indicated the presence of some interruption in the normal production of thyroid hormone rather than a deficiency of dietary iodine.

Group 3: The tissue was in a resting state. The lumina were distended with colloid to such an extent that the epithelium had become squamous. The addition of iodide had therefore fully compensated for the goitrogenic effect of the linseed meal.

Experiments with Sheep

A series of feed trials was set up for which 25 five-year-old Corriedale ewes were selected. After tupping, they were divided into seven groups. The rations of each of these groups were so arranged that each ewe received approximately the same daily weights of starch and protein equivalents. The daily, per-capita, maintenance diets of these groups were as follows:

Group 1: 0.33 lb. oats; 0.33 lb. linseed meal; approximately 1.0 lb. lucerne hay.

This was the same diet that produced the outbreak of goitre observed by Hart and Coop at Lincoln in 1951 (pers. comm.).

Group 2: Diet as for Group 1 with the daily addition of potassium iodide to the drinking water. The weight of added iodide was calculated as above and was found to be 11.4 mg. per sheep per day. This was reduced to 1.14 mg. potassium iodide per sheep daily for the last fortnight of pregnancy.

Group 3: Diet as for Group 1 with the daily addition of 40 mg. monosodium L-thyroxine to the drinking water of each sheep.

Group 4: Diet as for Group 1 with the daily addition, per sheep, of 0.25 g. of powdered 6-n-propyl-2-thiouracil mixed with the oats and linseed meal.

Group 5: 2 lb. lucerne hay only.

Group 6: 0.67 lb. peas; approximately 1.0 lb. clover hay.

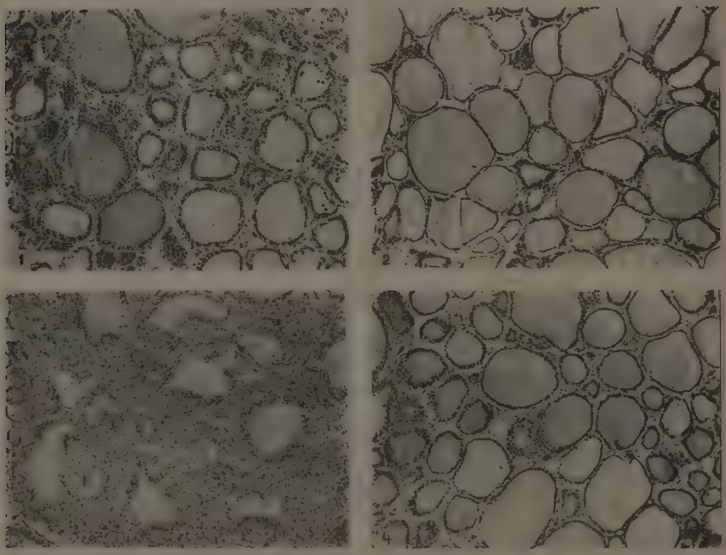
Group 7: 0.4 lb. linseed meal; approximately 1.3 lb. clover hay.
All groups were allowed access to unlimited drinking water. In order to avoid complications arising from pregnancy toxaemia, an endeavour was made to keep each ewe at a steady weight until the last month of pregnancy, when each ration was increased by one-third.

Three days after lambing, both ewes and lambs were killed and their thyroids excised, quickly dissected free from fat, muscle, and connective tissue, weighed, and fixed in 10% formol saline. Transverse sections from each thyroid were taken immediately after death for histological examination. The remainder of the glands were analysed for iodine in the following way:

Weighed amounts of each dried, chopped gland were digested with 10% aqueous caustic potash. Each residue was then partly ashed in a muffle furnace at 450°C., filtered through a Gooch crucible and made up to volume. Aliquots were taken and acidified with sulphuric acid, the potassium iodide oxidized to iodate with bromine vapour and the excess bromine removed with salicylic acid. Iodine was liberated by the addition of potassium iodide and this iodine was then titrated against standard sodium thiosulphate. By this method the amount of iodine contained in the original sample was augmented sixfold. The percentage iodine content was expressed on a dry-weight basis.

Results

Results are set out in Tables 1 and 2.



Figs. 1–4.—Typical thyroid tissue from ewes on different rations:
1. Oats, linseed meal, lucerne hay, in the ratio 1:1:3.
2. As for 1, with potassium iodide added.
3. As for 1, with the addition of 0.25g. of powdered 6-n-propyl-2-thiouracil per head.
4. Peas and clover hay in the ratio 2:3.

Discussion

From a statistical analysis of the iodine contents of fat-lamb thyroids collected throughout New Zealand, Waters (1939) showed that the critical percentage iodine content (on a dry-weight basis) was 0.10. Below this figure there existed an inverse relationship between the weight of the gland and its percentage iodine content. He considered that the range 0.10 to 0.19 was low, but that 0.20 and above was an indication of an adequate iodine level under New Zealand conditions. Since these

TABLE 1. HISTOLOGICAL EXAMINATION OF EWE THYROID TISSUE

Group	Fig.	Diet	Colloid Content	Description of tissue structure
1	1	Oats, linseed meal, and lucerne hay, in the ratio 1:1:3	Low	Epithelial cells of high cuboidal to columnar type. This indicated activation due to some interruption in producion of thyroid hormones, rather than to a low iodine intake.
2	2	As for Group 1, plus supplementary iodine	Plentiful	Flat epithelial cells; normal thyroids.
4	3	As for Group 1, plus propylthiouracil	Very low	Thyroid vesicles smaller than normal and crowded together. Epithelial cells of columnar or high cuboidal type. Most vesicles empty of colloid, and absorption of colloid round the edges of large vesicles. Appearance similar to that of human thyro-toxicosis.
6	4	Peas and clover hay	Plentiful	Appearance fairly normal except that the proportion of wedge-shaped nuclei was larger than normal and indicated some activation.

figures refer to fat lambs, those relevant to new-born lambs would be somewhat lower.

Analysing the sheep results on this basis, it would seem that all the groups, with the exception of 2, 3, and 5, are on a low or sub-critical iodine plane. This is due to either the presence of goitrogens in the diet, a low iodine intake, or perhaps a combination of both. Of these possibilities the presence of some goitrogenic action is indicated by the lower iodine contents and greater weights of the thyroids of the lambs of Group 1 compared with those of Group 5. This explanation is supported by histological examination of thyroids of the experimental mice and ewes.

An examination of many fruits and vegetables carried out by Greer and Astwood (1948) with the aid of radioactive iodine, indicated the presence of a goitrogenic factor in a wide range of vegetable families, including the pea. Therefore, the inclusion of peas in the diet of the sheep of Group 6 may account for the very low average thyroid iodine contents of their lambs and for the traces of activation noticed in their histological examination.

The evidence obtained indicates that linseed contains a goitrogenic factor, the action of which is suppressed by the addition of supplementary iodine to the diet. This factor is presumably the cyanogenetic glucoside, linamarin. If this be so, its effect is probably produced by the hydrolysis

of linamarin in the rumen and the subsequent detoxication of cyanide to thiocyanate in the liver (Blakley and Coop, 1949). Since thiocyanate is an iodide-responsive goitrogen, it follows that the effects of the addition of linseed meal to the animal diet may become apparent only under conditions of low total iodine intake. The incidence of goitre from this source may therefore be connected with rainfall and excessive leaching of iodine from the surface layer of soil.

TABLE 2. CORRELATION BETWEEN DIET AND THE THYROID IODINE CONTENTS OF EWES AND THEIR LAMBS

Group	Ewe Tag Number	Number of Lambs Born	Ewe		Lamb	
			Thyroid Weight (g.)	% Iodine	Thyroid Weight (g.)	% Iodine
1	A85	0	12.76	0.23	—	—
	B422	2	9.70	0.09	5.77	0.022
					10.89	0.019
	A4	1	16.24	0.16	11.30	0.026
	30/47	1	5.03	0.11	12.43	0.012
2	A106	2	5.07	0.71	0.62	
					1.05	
	A277	2	7.84	0.86	0.59	0.50
					0.59	
	A796	2	10.97	0.76	1.05	
					0.61	
3	102/47	1	5.78	0.35	0.60	
	11/47	1	6.44	0.51	1.30	0.43
	A359	1	4.40	0.43	0.77	
	B259	1	10.35	0.47	0.60	
4	207/47	1	52.61	0.017	14.70	0.018
	141/48	0	19.84	0.016	—	—
	B273	2	381.90	0.012	48.95	0.025
					35.72	
	A197	1	79.48	0.014	16.92	0.031
5	65/47	2	10.27	0.19	1.13	
					1.20	0.16
	48/47	0	5.51	0.31	—	
	B208	1	4.50	0.13	1.64	
6	121/47	1	6.21	0.12	1.50	
	0376	2	7.90	0.06	3.01	0.050
					3.15	
	256/47	1	5.24	0.15	3.14	
7	149/47	1	4.58	0.20	1.57	
	A196	0	6.39	0.21	—	0.063
	210/48	0	6.88	0.17	—	
	205/47	1	4.75	0.29	1.50	

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He also wishes to record his appreciation of the help and advice afforded him by Professor I. E. Coop and the staff of Canterbury Agricultural College. He is indebted to Dr. H. D. Purves and to Dr. W. E. Griesbach of the Endocrinological Research Unit, Dunedin, for their histological examination of the thyroid tissues concerned.

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MEASUREMENT OF FEED INTAKE BY GRAZING CATTLE AND SHEEP

VI. THE DETERMINATION OF CHROMIC OXIDE IN FAECES

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(Received for publication, 2 July 1954)

Summary

A method for the rapid determination of chromic oxide marker in faeces is described.

INTRODUCTION

Since the method previously in use at this Station for the determination of chromic oxide marker in faeces was described[1], the development of a more rapid method has been investigated. A wet digestion procedure was sought, because the various fusion methods available[2,3], involving a high wastage of crucibles and either neutralization or filtration, are not very convenient for handling the large number of samples encountered in our work.

The main difficulty in the determination lies in dissolving the chromic oxide. Digestion with mixtures of perchloric and sulphuric acids, even with control of temperature at 180–190°C.[4], did not prove satisfactory because of incomplete oxidation to dichromate. Procedures in which complete oxidation was performed by other reagents after initial solution with perchloric and sulphuric acids were too complicated.

It has been found that chromic oxide is much more readily attacked at higher temperatures than were used in the previous method. On heating with aqueous phosphoric acid up to about 200°C., chromic oxide reacts readily with a number of oxidizing agents, e.g., perchloric acid, chlorates, bromates, iodates, permanganates, bismuthates, dichromates, manganese dioxide, and lead dioxide, to form chromic acid. As the temperature is increased, however, the oxidizing power of the solution is lost, and reduction to the trivalent state takes place. Further heating leads to the formation of insoluble chromic compounds.

A mixture of potassium bromate, manganese sulphate, and phosphoric acid, has been found to be suitable for the digestion of faeces ash. Chromic oxide reacts at a lower temperature with bromate than with the other substances mentioned above, but bromate is rather quickly decomposed by the acid and by ash constituents. Any chromic oxide remaining is dissolved by the action of the dichromate already produced and the manganese present in an oxidized form.

Subsequent conversion to dichromate is then easily carried out by further bromate oxidation.

EXPERIMENTAL PROCEDURE

Dissolution and Oxidation

The ashed sample of up to 0.3g. ash weight and containing 1–15 mg. Cr_2O_3 is quantitatively brushed into a dry 150-ml. Erlenmeyer

flask with a camel-hair brush; 3 ml. of the mixture of phosphoric acid and manganese sulphate, and 3 ml. of bromate solution are added, and the flask is placed without delay on a hot plate which has been previously brought up to a temperature such that digestion occupies 7 to 15 min. and the boiling point of phosphoric acid is not reached. When effervescence ceases and the brownish colour of the solution changes to a deep violet due to oxidized manganese, the flask is removed immediately from the hot plate and allowed to cool for 15 to 30 sec. (If the solution turns green, an excess of Cr_2O_3 is indicated). Hot distilled water (20 to 30 ml.) is then rapidly added through a rosehead to prevent solidification of the digest.

Oxidation is carried out by adding 6 ml. of the mixture of sulphuric acid and manganese sulphate and 1 ml. of bromate solution, replacing on the hotplate with swirling and the addition of several fine chips of porous pot, and boiling for 5 min. at a volume of 30 to 40 ml., when the colour of the solution should be a bright orange-red due to the formation of free bromine. When the chromium concentration is high, a further 1 ml. of bromate solution may be added to expedite oxidation. More porous pot chips are added, the volume is increased to 50 to 70 ml., and 5 ml. of the clearing mixture are introduced. Boiling is continued for 10 min. At the end of this time the vapour should give no test with KI–starch paper and the flask is removed from the hotplate.

The time required for the entire operation is about 45 min., and 50 samples can be conveniently dealt with simultaneously.

Estimation of Dichromate

Reduction with arsenite and back titration with permanganate may be carried out as in the previous method[1].

Alternatively, the solution is titrated with ferrous ammonium sulphate, using an internal indicator. Ferroin (o-phenanthroline ferrous complex) is excellent for this purpose, but is rather expensive. N-phenylanthranilic acid is a highly sensitive indicator, but because of the nature of the colour change (purple to pale green) the end point must be approached slowly. The ferrous solution is run in till the mixture is pale yellow-green, one drop of N-phenylanthranilic acid solution is added, and the titration continued with shaking after the addition of each drop. The ferrous ammonium sulphate is standardized against 2 ml. of N/10 potassium dichromate diluted to 50 ml. and acidified with 3 ml. of concentrated sulphuric and 3 ml. of 85% phosphoric acids.

Reagents

Standard Potassium Dichromate: Exactly N/10 solution prepared from AnalaR Potassium dichromate dried at 150°c.

Potassium Bromate: 4.5% solution.

Phosphoric Acid/Manganese Sulphate Mixture: 30 ml. of a 10% solution of $MnSO_4.4H_2O$ in 1 l. of 85% (w/w) orthophosphoric acid.

Sulphuric Acid/Manganese Sulphate Mixture: 5 ml. of a 10% solution of $MnSO_4.4H_2O$ in 1 l. of 50% (v/v) sulphuric acid.

Clearing Mixture: 125g. ammonium sulphate and 70 ml. hydrochloric acid in 1 l. distilled water.

Ferrous Ammonium Sulphate: N/20 solution in 5% sulphuric acid.

Indicator Solution: 1.07g. N-phenylanthranilic acid dissolved in 20 ml. of 5% sodium carbonate solution and diluted to 1 l.

Several thousand samples have been analysed by this method during the last eighteen months. Reproducibility to within 2.5% is high. A thorough check has been made against the previous method[1] and the agreement is in all cases satisfactory, with no evidence of any bias between the analyses, either on faeces samples or on samples of chrome green pigment. No "blank" effects due to faeces ash constituents have been detected.

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PRELIMINARY FIELD TRIALS TO CONTROL BLAST OF STONE FRUIT (*Pseudomonas syringae* van Hall.)

By D. W. Dye, Plant Diseases Division, Department of Scientific and Industrial Research, Auckland

(Received for publication, 28 July 1954)

Summary

Field trials were carried out in mid winter, late winter, and early spring, to determine the effect of streptomycin sulphate, Flit 406, Dithane Z78, and Bordeaux mixture in preventing infection of peach trees by *Pseudomonas syringae*.

Trees were wounded, sprayed with therapeutants and, when dry, inoculated with *Ps. syringae*.

Streptomycin sulphate gave a high degree of protection in all trials. Bordeaux mixture and Flit 406 reduced infection slightly in two trials, while Dithane Z78 gave inconclusive results.

There appeared to be an increase in susceptibility of peach seedlings to attack by *Ps. syringae* when spring growth commenced.

Introduction

Glasshouse tests previously reported (Dye, D. W., 1953; Dye, D. W. and Dye, M. H., 1954) have shown the superiority of streptomycin sulphate over other therapeutants for the prevention of blast of stone fruit (*Pseudomonas syringae* van Hall) on peach seedlings under controlled conditions. As a preliminary to orchard and nursery trials, three small field trials were carried out at Auckland during 1953 using methods similar to those used in the glasshouse. These were commenced at three periods of the year: (1) mid winter; (2) late winter just prior to obvious bud movement; and (3) early spring when plants were showing green and pink tip bud movement. These times were chosen in order to obtain conditions in one or all trials which were thought to be favourable for the blast organism.

Materials and Methods

The materials tested in all three experiments were:

1. Streptomycin sulphate at a concentration equivalent to 180 p.p.m. streptomycin base;
2. Flit 406 (50% N trichloromethylthio-tetrahydrophthalimide) 2 lb. per 100 gal.;
3. Dithane Z78 (65% zinc ethylene bisdithiocarbamate) 3 lb. per 100 gal.;
4. Bordeaux mixture (copper sulphate, hydrated lime, water) 6-8-100;
5. Check: water.

Trial 1 commenced on 23 June on dormant Black Boy peach seedlings approximately 12 in. high. Plants were wounded at three points on the south side of the stem with an instrument which made punctures in the bark up to 1.5 mm. diam. Immediately after wound-

ing, plants were sprayed with a solution or suspension of test substance in water. When dry, they were sprayed with a broth culture of a pathogenic strain of *Ps. syringae*. Inoculum was prepared by growing the organism for 24 hr. at 28°C. in Difco nutrient broth plus 0.5% glucose. The layout used was 6 trees per plot, and 5 plots per block, treatments being randomized within each of 10 blocks.

The weather on 23 June was mainly overcast with maximum and minimum air temperatures of 63.9°F. and 39.3°F. respectively. Relative humidity at the time of inoculation was 98%. No rain fell for 5 hr.

Fig. 1.—Effect of streptomycin in preventing development of blast of stone fruit. Streptomycin-sprayed twig (left) shows 7 negative wound points and normal growth. Water-sprayed check twig (right) shows 8 positive lesions which have joined and almost killed the twig. Note also gum exudate at base of check twig. Photograph taken 35 days after treatment.

Photo: H. E. Powell

after inoculation, but light rain fell on each of the following 7 days, a total of 1.85 in. being recorded. In the same period, average maximum and minimum air temperatures were 57.5°F. and 40.3°F. respectively and the average 9.0 a.m. relative humidity was 88%.

Trial 2 was laid down on 31 August using unpruned 1-year-old Stark peach trees on Levis Cling peach stocks, which were showing no sign of bud movement. Each of four branches per tree was wounded as in Trial 1, at 10 points approximately 1 cm. apart. Treatments similar to those in Trial 1 were applied to 6 trees per treatment, followed by inoculation as already described.

The weather on 31 August was overcast, with maximum and minimum air temperatures of 57.8°F. and 42.2°F. respectively. Light rain began falling 1 hr. after inoculation and further rain fell on each of the following 7 days, a total of 1.54 in. being recorded. In the same period average maximum and minimum air temperatures and the 9.0 a.m. relative humidity were 62.8°F. and 52.4°F. and 97% respectively.

Trial 3 commenced on 8 September on the remaining half of each tree used for Trial 2. By this time bud movement had commenced and many trees were showing "green and pink tip". Wounding, treatment, and inoculation were the same as in Trial 2, each tree receiving the same treatment material that it received in Trial 2. The weather on 8 September was partly cloudy with maximum and minimum air temperatures 60.3°F. and 55.5°F. and relative humidity 73%. No rain fell for 53 hr. after inoculation and the total rainfall for the next 7 days was 0.53 in. on 4 days. During this period average maximum and minimum air temperatures and 9.0 a.m. relative humidity were 60.1°F., 48.3°F., and 81%, respectively.

RESULTS

Clearly visible lesions did not develop in check trees of Trial 1 until 58 days after inoculation. At this stage results were recorded as the number of positive lesions per tree. Lesions developed more quickly in check trees of Trials 2 and 3, and records were taken of these trials, 43 and 35 days respectively after inoculation. Results are shown in Table 1 and Fig. 1.

Results show that streptomycin sulphate gave a high degree of protection against blast of stone fruit in all three trials and was outstandingly superior to the other three therapeutants. Bordeaux mixture and Flit 406 did not give significant control in Trial 1 but in Trials 2 and 3 gave control that was significantly better than check at the 0.1% and 1% levels respectively. Dithane Z78 gave an inconsistent result since it was not significantly different from check in Trials 1 and 3, but gave a highly significant difference in Trial 2.

DISCUSSION

The conditions of these trials can be regarded as more severe than would normally occur in orchards or nurseries, and temperature and humidity conditions in each trial were considered to be favourable for attack by *Ps. syringae*. The highly significant control given in all trials by streptomycin sulphate indicates that this material is worthy of trials under orchard and nursery conditions. Control secured with Bordeaux mixture when applied just prior to or at bud movement, although considerably less than that by streptomycin sulphate, would justify its use in the field

TABLE 1. THE EFFECT OF THERAPEUTANT SPRAYS IN PREVENTING BLAST OF STONE FRUIT IN PEACH TREES

TREATMENT	Trial 1 23/6/53—20/8/53		Trial 2 31/8/53—13/10/53		Trial 3 8/9/53—13/10/53	
	Number of positive lesions*	Means of equivalent angles	Number of positive lesions†	Means of equivalent angles	Number of positive lesions†	Means of equivalent angles
1. Streptomycin sulphate 180 p.p.m.	28	21.97	35	15.99	59	26.33
2. Flit 406 2 lb./100 gal.	87	44.02	175	61.07	200	70.10
3. Dithane Z78 3 lb./100 gal.	85	43.35	162	57.95	214	76.04
4. Bordeaux mixture 6-8-100	97	48.90	143	51.50	180	62.77
5. Check (water)	127	58.20	199	71.43	229	83.76
Differences necessary for significance 5%		15.30		8.49		8.20
1%		20.40		10.10		10.83
0.1%		26.49		11.22		13.96

* Number of wounds 180
† „ „ „ 240

if confirmed by further tests. This result was not obtained in the glasshouse trials (Dye, D. W. and Dye M. H., 1954). The difference could have been caused by spray damage when Bordeaux mixture was applied to peach seedlings in full leaf. In the present trials, trees were leafless and showed no signs of spray damage.

Neither Flit 406 nor Dithane Z78 provided effective protection and no explanation can be given for the inconsistent result obtained with the latter material.

Number of lesions in relation to number of wounds was assumed to be a measure of bacterial activity. A comparison of Trials 2 and 3, separated by only 8 days, shows that when spring growth commenced (Trial 3) there was more infection than when trees were apparently dormant (Trial 2). Since temperature and humidity conditions did not vary greatly between these two trial periods, the increase in infection suggests some change in susceptibility of plants to *Ps. syringae*. If this is true, it has an important bearing on application of treatments to control blast of stone fruit.

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THE HIGH-ALTITUDE SNOW-TUSSOCK GRASSLAND IN SOUTH ISLAND, NEW ZEALAND

By The Tussock Grassland Research Committee

(Received for publication, 17 August 1954)

Summary

This review by an interdepartmental committee summarizes what is known of the scientific aspects of high altitude snow-tussock grassland. Available information about plants and soils records deterioration of this vegetation to the detriment of adjoining protection forests and the land below. It is concluded that research along specified lines is urgently needed to find possible methods of rehabilitation. Meanwhile every effort should be made to slow down deterioration by reducing burning and grazing. Appendices deal with the different kinds of *Danthonia* tussock, the land tenures affecting this country, and the literature on the subject.

Introduction

The Tussock Grassland Research Committee was set up in 1952 on the initiative of the then Assistant Secretary (now Secretary) of the Department of Scientific and Industrial Research. It is composed of research workers in tussock grassland problems from the Departments of Agriculture and Scientific and Industrial Research, the New Zealand Forest Service, and the Soil Conservation and Rivers Control Council, and an administrative officer of the Department of Lands and Survey.

The committee meets periodically to exchange views on the various problems and to co-ordinate research on the tussock grasslands.

The body of this review has been prepared by the following members of the Committee, T. G. Sewell, Department of Agriculture, Chairman; J. T. Holloway, New Zealand Forest Service; L. B. Moore, J. D. Raeside, Department of Scientific and Industrial Research; S. H. Saxby, Department of Agriculture; H. E. Connor, Department of Scientific and Industrial Research, Secretary; B. E. Ussher, Department of Lands and Survey, contributed Appendix III on high-country land tenures.

The high-altitude snow-tussock grassland was selected as the first subject for study because it is considered to be one of the most important vegetation units in the Dominion on account of its inherent instability and advanced state of deterioration (Fig. 1). It has been everywhere most neglected by research workers. This present paper brings together the substance of published reports, and supplements these with the technical information available to the Committee with respect to a certain portion of the snow-tussock grasslands. The result reveals how little is recorded or accurately known about this part of the country, which is closely related to the adjoining protection forests, and has a direct and at times disastrous influence on all land below.

"Snow tussock" and "snow grass" are names generally applied to large yellowish-green tussock grasses of the genus *Danthonia*. Here the term "snow tussock" is preferred and is applied more precisely to the species *D. flavescens* Hook. f. (Fig. 2), as distinct from red tussock (*D. rigida* Raoul) and other coarse tussock grasses of the genus

Danthonia. The grassland that is characterized by the dominance of this snow tussock is one part of what Cockayne (1928) designated "tall tussock-grassland", which he contrasted with "low tussock-grassland". His "low tussock-grassland" includes what is referred to in this paper as fescue-tussock grassland.

Fig. 1.—Severely eroded snow-tussock country on the upper slopes, 4,000 to 6,000 ft. altitude, of the Craigieburn Range, Waimakariri River catchment. At no time would the cover of vegetation have been complete. Screes were always a feature of steep slopes at these altitudes. But these screes have undergone rapid and recent extension, and as shown by the extent of bare Kaikoura subsoil must undergo still further extension. Remnant subsoils may still be found in pockets close up under the summit of the range.

These slopes are still grazed by sheep, deer, and chamois. There is a heavy population of hares. (Photo. N.Z. Forest Service 1952).

Fig. 2.—Snow tussock, the dominant plant of the tall-tussock grassland, on Kaikoura loam, upper Awatere Valley. (Photo. Soil Conservation Council)

The snow-tussock grassland here considered is that which is found on South Island mountains between approximately 2,500 ft. and 6,000 ft., though the lower limit is rather higher towards the north (Fig. 3). The discussion refers only to those areas where slopes are rather steep and the soils belong mainly to the Kaikoura series. The total area so delimited is estimated to be five million acres.

Excluded from this discussion are areas dominated by red tussock (*D. rigida*), e.g. in Southland; snow-tussock grassland on moraines and terraces in the mountains; and low-altitude snow-tussock grassland on easier often ploughable slopes as in parts of east Otago. This last is dominated by *D. flavescens* but differs from high-altitude snow-tussock grassland in that it includes a much greater proportion of introduced plants, and is on different soil types; here, in places, the original vegetation has been deliberately destroyed in order to replace it with an entirely different group of plants for pasture or occasionally for crops.

ECOLOGY

General

Little has been written about the ecology of the snow-tussock grasslands. In 1928 Cockayne summarized in two pages his own earlier work and the results of Allan's study on Mt. Peel (1926). Since that date there has been only one botanical paper (Barker, 1953) where snow-tussock grassland is discussed as a separate unit. One difficulty is that the species of plants involved are not well known. Cockayne said in this connection, "it is hopeless to really understand the ecology of a community until the taxonomic status of its members is understood—

Fig. 3.—Distribution of snow-tussock grassland in South Island, New Zealand. (Prepared by J. D Raeside.)

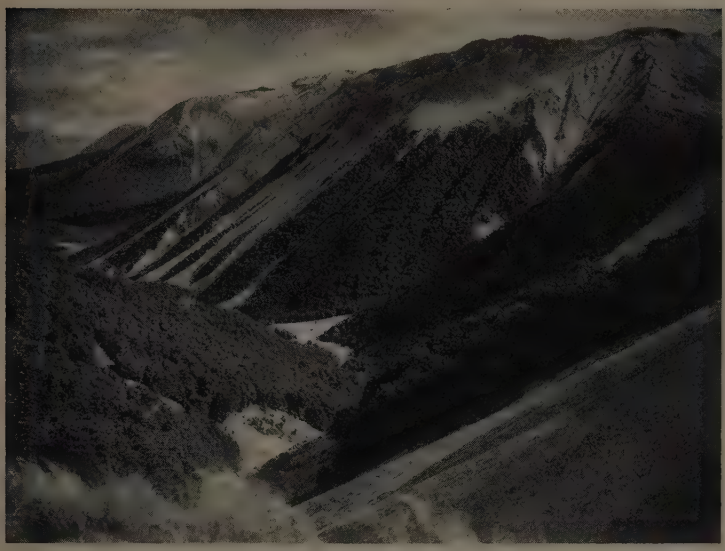

Fig. 4.—Upper valley, east branch of Harper River from Cass Saddle. Snow-tussock 'basins' lying above *Nothofagus cliffortioides* protection forest which has been in part destroyed, and is elsewhere threatened, by gully erosion and scree movement consequent on degradation of the grassland.

The scree slope, right foreground, is known to have carried remnant snow tussocks in 1948, to have been a slope of bared subsoil in 1950, and to have been mantled with moving rock waste in 1952. (Photo. N.Z. Forest Service, April, 1953).

Fig. 5.—Snow-tussock grassland on Kaikoura soils, Ben McLeod Range, Rangitata Valley, 4,000 ft., showing active erosion on slope of 33°. Rocky debris is streaming downhill. Camera is pointed sharply upwards. (Photo J. D. Raeside, October, 1942).

a matter almost invariably neglected by plant ecologists". Another difficulty is that precise climatological data are wanting, as no meteorological stations are located well within the areas discussed in this paper.

The snow-tussock grassland may present from a distance (and it is mostly observed from a distance) the appearance of a complete cover. The undisturbed grassland was a closed vegetation, but 90 years of pastoral occupation has changed it catastrophically. On closer inspection it is now found that the area of bare ground in most places is greater than that covered by the tussocks.

Large parts of the snow-tussock grassland have been converted to rapidly moving wastes of scree which have mostly started near the upper parts of mountain sides and in some places have descended into plant communities at lower altitudes, e.g. fescue-tussock grassland, and forest (Fig. 4). Forests cannot withstand the movement of active screes, and where invaded cannot be regenerated until the scree is controlled and stabilized.

The instability of the soil is the most important edaphic factor in the ecology of the snow-tussock grassland in its present altered state, and is also of prime importance in relation to current management (Fig. 5).

The soil and the vegetation are closely interdependent, and a change in the one is followed by a change in the other. Thus burning the tussock induced changes in the soils through erosion, which induced a further change in the grassland, and this in turn increased the rate of erosion.

Soils

High-altitude snow-tussock grassland occurs mostly on Kaikoura soils (Gibbs *et al.*, 1945). Small areas occur on Haast soils in the Southern Alps and a few occurrences have been noted on shaded slopes of Hurunui soils. The Haast soils are only slightly eroded, because there has been almost no burning or grazing; and the area of Hurunui soils carrying snow tussocks is small and practically uneroded, so that discussion of the soil factor will be confined to the Kaikoura soils. By far the greatest area of snow-tussock grassland lies on steep slopes, where the problems of erosion and grassland management are most acute.

The Kaikoura soils belong to the group of yellow-brown earths, and are derived from indurated greywackes and mica schists. They have affinity with the leached brown earths of Europe and with some of the brown podzolic soils of North America. They are characterized by silt loam textures throughout the profile, yellow-brown subsoils, and weak crumb structures throughout. The Kaikoura soils have developed in a cool sub-alpine and alpine climate under annual rainfalls of 35 to 75 in. Winters are cold with much snow and severe frosts, and in general the lower boundary of the Kaikoura soils coincides with that of winter snow. Much of this tussock grassland may be covered by more or less continuous snow for two to three months. Summers are warm and dry with many north-west föhn-like winds.

Possibly the element of climate that has the most profound effect on the stability of the soil profile is frost. Frost action is widespread and intense for at least nine months of the year and both rocky fragments and fine particles are moved downslope by frost disturbance and gravity.

The movement on steep slopes is rapid and extremely destructive of the soil profile. The following frost phenomena have been observed:

Frost Pillars. Frost pillars or needle ice are elongate ice crystals which grow perpendicular to the surface of the soil and lift small soil masses and stones by as much as 3 in. When the ice melts, the lifted soil moves downslope under the pull of gravity. The mass lifted over each square inch of surface is probably small but appreciably augments the cumulative downhill creep of topsoil and discourages the growth of young shallow-rooted plants even on flatter surfaces.

Stone Lift. A common phenomenon after a succession of heavy frosts is the lifting of stones and pebbles by local heaving of the upper horizons. During the thaw the subsidence of the fragments of rock is accompanied by a downslope movement greater or less according to the angle of slope and the extent of the "lift".

Soil Striations. Soil striations are alternate strips of fine and coarse debris, directed downslope, and commonly resting on a corrugated surface of soil or subsoil. The striations are spaced from 3 to 5 in. apart and the "channels" in which the coarse debris rests may be up to 2 in. deep. They form best on slopes between 3° and 8°. On steeper slopes the rate of creep is faster and the debris moves as a heterogeneous mass of subsoil and rock fragments, in which all trace of the striations is lost. Striations once formed are an unfavourable environment for the germination of seed owing to the movement of the stony debris and the likelihood of seedlings being uprooted.

The net effect of frost action is to move the soil mantle downhill, the downhill displacement being greatest at the surface of the ground and decreasing downwards.

The following properties of the Kaikoura soils have an important bearing on their susceptibility to erosion:

Structure. The topsoils possess a weakly developed crumb structure, but are very friable and easily broken down by frost, by the impact of raindrops, by the trampling of animals, or even by strong winds. Probably the most destructive agency is frost, which totally destroys the structure. Subsoil structures are somewhat stronger than those of the topsoil, and the subsoil offers slightly more resistance to disintegrating forces.

Texture. The texture of both topsoil and subsoil ranges from silt loam to sandy silt loam with most profiles containing somewhat more sand than a modal silt loam. As the altitude increases, the proportion of sand increases also, and at 5,500 ft. the texture may approach a loamy sand or even a coarse sand. Textures within the silt loam range are easily eroded by wind and water, and are also those in which frost heave is most active. Frost heave loosens the profile and prepares it for erosion. Kaikoura soils, if left undisturbed for some years under snow tussocks standing 3 ft. high or more, possess an organic horizon of from half to one or two inches of peaty leaf litter. This consists of fallen leaves showing progressive decomposition downwards into a dark, wet, compressed mass which is sharply contrasted with the underlying mineral soil. Such sparse records as are available indicate that this organic layer must have been at least 6 in. thick in the original undisturbed grassland. At present

it is wanting on all but a few shaded slopes that have been left undisturbed for many years.

Drainage. The profile of the Kaikoura soils is loose and porous and they therefore drain freely. Runoff is rapid, and the shallow soil might be expected to suffer from drought during periods of high evaporation especially where the surface is bare.

Natural Fertility. The soil is strongly leached (base saturation 15% to 30%) and both topsoil and subsoil are moderately acid (pH 5.0 to 5.5) with a slight increase in acidity in the subsoil. Calcium figures are low and fall very sharply in the subsoil, while phosphate and potash figures appear to be adequate in the topsoil but fall sharply in the subsoil. This lower fertility in the subsoil is important for any regrowth of plants, since practically none of the original topsoil of pre-European days now survives. No study has been made of the soil biology, but the extreme changes in soil stability, temperature, and moisture, would be expected to have a profound effect on the soil flora and fauna. Leguminous plants are almost totally wanting and there is no information whatever concerning the nitrogen cycle.

Profile Stability. On slopes of 30° and over, and even under a closed cover of vegetation, the soil mantle is subjected to some downslope movement. Now that the vegetative cover is reduced, frost, high winds, and the increased wetting and drying of the soil increase the downslope movement, and scree is the ultimate result in many places (Kingsbury, 1954).

Thickness of Soil Mantle. The parent rocks—greywackes and mica schists—weather slowly in the climate of South Island highlands, and the gain from weathering does not exceed the loss from wastage as it does in parts of North Island. The soil mantle is therefore thin, rarely exceeding 20 in. even on shaded and gentle slopes. Under accelerated erosion, the loss through wastage greatly exceeds the gain from weathering of the parent rock, and the soil mantle is correspondingly thinner; it is in fact scarcely a soil mantle, but rather a slowly moving stream of debris, a mixture of topsoil, subsoil, and unweathered fragments of rock. Shallow profiles have a two-fold influence on vegetation. Root development is restricted—an important limitation for the snow tussock which is naturally a deep-rooted plant, roots having been traced to a depth of 2 m. (Barker 1953)—and the moisture reserve is limited. There is no information concerning the capacity of snow tussocks to withstand drought during the different phases of their life history.

In considering the effect of any set of soil conditions on the stability of a plant community, it must be kept clearly in mind that for a plant to thrive, and, what is more important, to multiply, that soil must be able to provide: (1) stable environment for roots; (2) adequate supply of moisture; (3) sufficient nutrients at all seasons. The capacity of the eroded Kaikoura soils to fulfil these demands will determine the future of the snow-tussock grassland. In its primitive state, the peaty litter and the canopy of the tussocks assisted the soil to fulfil the first two requirements, but now all three are less adequate; in fact, in the dry mountains and at altitudes over 4,000 ft. the minimum needs are not met and complete destruction of the snow tussock has occurred or can be expected.

Floristics

Floristic Lists. Little has been written about the floristic botany of the high-altitude snow-tussock grassland. Allan (1926) provides a list of species found in the snow-tussock grassland association at Mt. Peel, South Canterbury, and this list agrees well with that of Barker (1953) for Hunters Hills, South Canterbury, fifty miles further south. No other published lists are known, but much the same range of species occurs in limited areas examined in the vicinity of Dampier Range, upper Rakaia River, upper Avoca River, and Grampian Mountains, all in inland Canterbury. Important species are *Danthonia flavescens, Celmisia spectabilis, C. lyallii, Gaultheria depressa, Poa colensoi, Festuca novae-zelandiae, Anisotome aromatica, Leucopogon fraseri, Luzula campestris, Gentiana* spp. *Geranium sessiliflorum, Raoulia subsericea.**

Barker (1953) analysed snow-tussock grassland at Hunters Hills, by plant sociological methods. She lists in Table 8 twenty-two species found in the *Danthonia-Celmisia* alliance but not in fescue-tussock grassland. An extension of these same methods to other places would provide a sound basis for comparison and classification of tussock grasslands.

Exotic Plants. One outstanding difference between the responses of fescue-tussock grassland and snow-tussock grassland to pastoral use is the part played by exotic plants. Exotic plants have come to form an important part of the fescue-tussock grassland in number of species and of individuals, whereas in the snow-tussock grassland they are insignificant. In North Island Zotov *et al.* (1938) record only one exotic species (*Hypochaeris radicata*) above the forest line in the Tararua Range. Druce (pers. comm.) has definite records for only three exotic species in snow tussock above the timber line throughout North Island mountains—*Hypochaeris radicata, Taraxacum officinale,* and *Rumex acetosella,* all present in insignificant numbers.

Barker (1953) lists no exotic species for snow-tussock grassland that is not found also in fescue-tussock grassland. All except *Rumex acetosella* occur more widely at low altitudes. Her list includes, besides the *Hypochaeris* and *Rumex* mentioned for North Island, *Anthoxanthum odoratum, Holcus lanatus, Agrostis tenuis, Trifolium repens, T. dubium, Cerastium caespitosum,* and *Hieracium pilosella.*

Allan (1926) lists the same first five species, rated from frequent to local on Mt. Peel, and the same species with the exception of *Holcus lanatus* are found in the Waimakariri basin. Snow-tussock grassland areas examined at Molesworth (Marlborough) yield no additional species, and *Anthoxanthum* and *Holcus* seem there to be missing. Packard (1947) mentioned *R. acetosella* as the only exotic plant present in quantity in the high-altitude flora in the Lake Coleridge catchment. Some other exotic species are found as odd plants in snow-tussock grassland, but those providing any effective proportion of the plant cover are a bare half dozen.

The paucity of exotic plants accounts in part for the present state of the high-altitude snow-tussock grassland. It is obvious now that when the primitive cover was first broken no native plant was well equipped

*Few of the native plants of the snow-tussock grassland have widely known common names. Those most generally used are listed in Appendix II.

Fig. 6.—Moasic of plant communities, Torlesse and Craigieburn ranges. (Prepared by T. G. Sewell, 1950.)

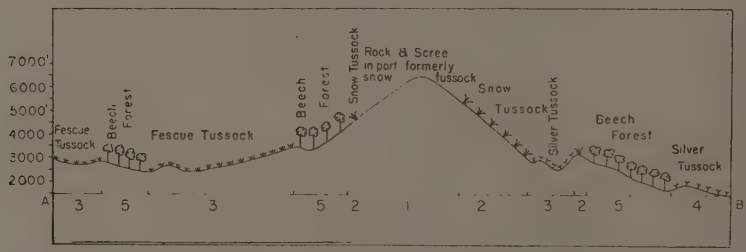

Fig. 7.—Diagrammatic line transect across Torlesse Range showing distribution of main vegetation units. Note: Numbers refer to legend of Fig. 6. (Prepared by T. G. Sewell, 1950.)

to fill the gaps. Had any of the available exotic species been capable of quickly covering the bare ground, irreversible loss of topsoil would not have occurred. Certainly not one of the species present, indigenous or introduced, effectively colonizes the subsoil once it is exposed between moribund snow tussocks—except, in certain parts of the high country, the pastorally undesirable *Celmisia spectabilis*.

Distribution of Snow-tussock and Adjoining Plant Communities

Snow-tussock grassland is widely distributed throughout the mountains of South Island, between 2,500 ft. and 6,000 ft. Altitudinal vegetation belts are marked (Fig. 6, 7); fescue-tussock grassland generally occupies the lower slopes, and usually gives way to snow-tussock grassland which is succeeded by herb- or fell-field. In the wetter districts, forest adjoins snow tussock on parts of the mountain sides. It is usual

for the belt of snow tussock to extend progressively lower as the aspect changes from north to south.

The diversity of altitudinal sequence can be illustrated by some examples. In the Waimakariri basin, Tawera County, snow tussock gives place at high altitudes (about 5,000 ft.) to *Podocarpus nivalis,* which grows on the scree that characterizes the uppermost slopes. On shaded faces it gives way to fell-field with species of *Celmisia, Brachycome, Drapetes, Phyllachne, Raoulia,* and *Danthonia.* These are mostly low-growing dense plants found in damper places. Under high rainfall, snow tussock gives place below to beech forest, which if burnt is usually replaced by silver- and fescue-tussock grassland with much of the exotic species *Anthoxanthum odoratum, Holcus lanatus,* and *Hypochaeris radicata,* and with some indigenous species, mainly of *Danthonia,* on the sunny faces; on shaded slopes, beech forest may pass into snow tussock through an intermediate belt of scattered scrub which includes *Dracophyllum* and *Cassinia.*

In other places near the main divide where rainfall is very high, snow-tussock grassland lies above a sub-alpine scrub belt of *Olearia–Dracophyllum* which bounds a *Libocedrus bidwillii–Podocarpus hallii* forest. Nearer to the east coast, below snow tussock, there may be either beech or podocarp-broadleaf forest with associated species of *Nothopanax, Pittosporum, Aristotelia, Pseudowintera,* and *Suttonia.*

Changes in Plant Communities

Changes in snow-tussock grassland have been mainly in the direction of deterioration. Reporting on field work done as late as 1922, Allan (1926) could refer to the "rather open association" on the exposed sunny slopes facing the Rangitata contrasted with the "completely closed association" on the more sheltered and shaded southward-facing slopes, while on the steep sunny and windy slopes leading to the main divide on Mt. Peel "the ground between the tussocks may be almost bare". There is no later report on this same area but there are few parts of Canterbury known to the Committee where a completely closed snow-tussock community is to be seen now, and in most places there is no doubt about the bare ground between the tussocks. Fig. 8 represents snow-tussock grassland near Porter's Pass. Here the average basal diameter of a snow-tussock plant is about one foot, centres are about six feet apart, and the canopy seldom exceeds three to four feet in diameter even under favourable circumstances. Inter-tussock plants are few, mostly crowded near the base of the tussock, and of little protective value to the soil surface.

In certain types of places snow-tussock grassland has been invaded by *Festuca novae-zelandiae* (Fig. 9), *Poa colensoi,* or *Celmisia spectabilis.* These three invaders, all of which existed to a small extent in the primitive snow-tussock grassland or on its margins, have become in places dominant species.

Festuca novae-zelandiae. Sites suspected of having been invaded by fescue tussock lie mostly below the present lower limits of snow tussock; here *Poa colensoi, Raoulia subsericea, Leucopogon fraseri, Celmisia spectabilis, Triodia pumila,* and *Gaultheria depressa* may be found. These plants may be taken as probable indicators of the former existence of snow-tussock grassland.

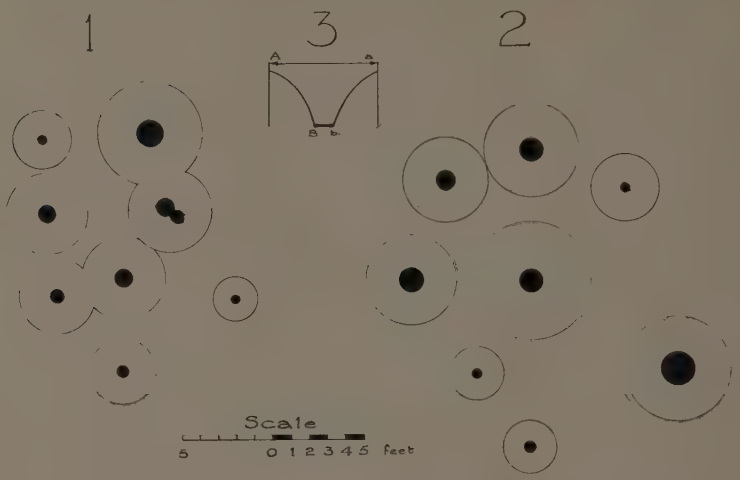

Fig. 8.—1 and 2 diagrammatic sketches to scale of basal areas, canopy spread and intertussock distances at two sites in snow-tussock grassland, near Porters Pass, inland Canterbury. Shaded portions are the bases and the unhatched portions are canopy spread. In nature neither the base nor the canopy spread of a snow tussock is strictly circular. 3. The method of measurement is shown in section. A—a, canopy spread; B—b, basal diameter. (Prepared by H. E. Connor, November, 1953).

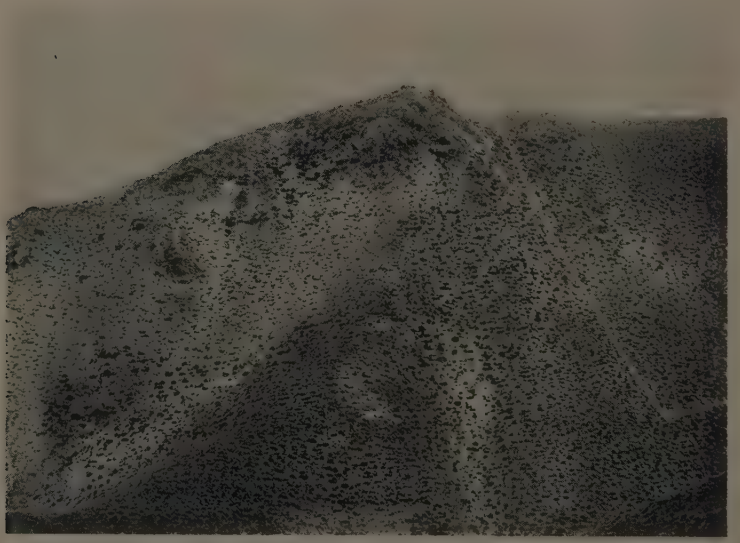

Fig. 9.—Lindis Pass, 3,500-4,000 ft. Original snow-tussock community has been invaded by fescue tussock. The fence encloses an experimental plot which was laid down in 1946. (Photo. J. D. Raeside, November, 1951).

Poa colensoi. Cockayne (1928) states that on the wetter mountains of south Otago at about 3,500 ft. a belt of *Poa colensoi* gradually appears replacing snow tussock. In wetter western valleys, e.g. Ahuriri Valley, on slopes of Mt. Gladwich, *P. colensoi* has invaded widely, and Allan records its increase following fire at 4,500 ft. on Mt. Peel.

Celmisia spectabilis is a common invader of snow-tussock grassland. Its most important character, and that which ensures its survival, is its capacity to tolerate drought and to survive fires better than other members of the community. This is probably because the leaf sheaths which shield the growing point are covered with a dense cottony tomentum which remains moist even in mid-summer. The destruction of the snow-tussock leaves by fire is a much greater set-back to that plant than is scorching to *Celmisia spectabilis.* Hungry sheep will eat the fresh growth of the snow tussock but do not eat even the young leaves of *Celmisia;* sheep seem to avoid areas where *Celmisia* is dominant. The extensive use of fire in snow-tussock management in the past has, therefore, induced a widespread invasion of the snow-tussock grasslands by *Celmisia.* In some places, notably on the eastern mountains of Canterbury, especially on shady faces, it has wholly replaced the snow tussock. Further to the west it occurs on shady southerly slopes, but is rarely found on sunny faces except in damper or flatter sites.

Cockayne's record (1920) on Little Mt. Peel where *C. spectabilis* was more abundant on the more leniently grazed side of a fence seems to be an isolated case to be explained by earlier treatment rather than by current grazing.

Relict Status of Snow-tussock Grassland

Raeside (1948) and Holloway (1949, 1954) have postulated that the present climate of New Zealand has succeeded an earlier warmer and wetter climatic cycle which ended probably 6 or 7 centuries ago. During this earlier climatic cycle, forest covered a considerable area of the downlands and lower mountain slopes that now support fescue-tussock grassland. Islands of snow tussocks above the present limit of closed vegetative cover, and the invasion of the snow-tussock community by fescue tussock, indicate that the snow-tussock grassland survived from the previous warm wet period, and, at least on the mountains surrounding the inland basins, is no longer in equilibrium with its environment, and is in fact relict grassland.

Festuca novae-zelandiae invaded the snow-tussock community possibly because of its ability to survive under drier conditions; but if this had been the only reason for invasion, and snow tussock was a climax association, some regeneration of the snow-tussock community would be expected. The notable rarity of seedling snow tussocks and the observed failure to survive of a few seedlings that have been noted (Barker 1953) reinforce this view; and the progressive deterioration of snow-tussock grassland even where it has been protected from fire and disturbance by grazing animals is additional support. If the snow-tussock grassland is relict, then the blanket of leaf litter and the large canopy of living leaves assume an even greater edaphic importance. They not only buffered the soil against frost, erosion, and drought, but also delayed readjustment of the plant community to the changed climate, and their

destruction initiated, over and above the present cycle of accelerated erosion, an irreversible readjustment of the vegetation. In the drier parts of the grassland, and above 4,000 ft., it seems likely that this readjustment is taking the form of extinction of the snow tussocks. On these sites, however, the changes in the soil factor have tended towards the same end. Whether the snow-tussock grassland is relict or not, the outcome on these sites will probably be its ultimate destruction; but if the relict hypothesis is correct the rate of extinction will be much greater, for, to the unfavourable edaphic conditions will be superadded an unsuitable climate.

Grazing and Burning

Merino and Merino-crossbred sheep have been pastured in the snow-tussock grassland since 1860. The usual procedure is to depasture this grassland in summer only; if there are sufficient north-west faces on which the snow melts quickly, these are utilized for part, or, on some stations, for the whole of the winter. The winter snow-line determines the length of winter grazing. Snow-tussock grassland is mainly used in large blocks of 5,000 to 20,000 acres over which the sheep forage widely at will. Information about the relative palatability of the plant species grazed is wanting, but available evidence, though not absolutely conclusive, indicates that the snow tussock itself is grazed only under exceptional circumstances such as during a snow-fall when all other plants are covered, or when a station block is greatly overstocked. Continued grazing is possibly more destructive of the accompanying smaller palatable plants than of the snow tussocks themselves. It has been pointed out (Barker 1953) that much of the forage is probably obtained by sheep from localized seepages, and other patches on ridge tops and ground of easy slope not typical of the snow-tussock grassland.

Sheep have an important physical effect on soil. In the early stages of erosion where topsoil and subsoil are exposed, and before appreciable downhill movement of waste has taken place, sheep do most damage in spring and summer. At these times the soil is loosened by frost, and trampling crushes the surface layers to dust, which is readily blown or washed away. When erosion is far advanced, and areas of loose moving rocky debris are appreciable, the trampling effect is greatly accentuated. The angle of repose of angular rocky debris or scree is about 33° and most mountain slopes approximate this. The passage of sheep over such a mass of scree disturbs the equilibrium and a great downhill movement may take place before a new state of equilibrium is reached.

In the present eroded state of the soils and the unstable and open state of the vegetation, it is questionable whether grazing of sheep in the high-altitude snow-tussock grassland is justifiable.

The damage done by heavier grazing animals such as deer and cattle is correspondingly greater, and in the interests of soil conservation it is important to ensure that the critical grasslands are protected from such animals.

From a short-term pastoral point of view fire is of first importance in the management of the snow-tussock grassland. Without first opening the tussock community by fire it would have been impossible to work it. Cockayne said in 1921 "The association, when fully developed, may

consist of little else than a dense green mass of tussocks not easy to penetrate. This has led to the destruction of the original association in many places through periodical burning by musterers in order to make paths for bringing down the sheep from alpine pastures." Had fire not been used, this grassland would have remained more or less intact except in so far as it is a relict out of equilibrium with the environment and therefore in a state of slow but inevitable readjustment.

The effects of fire are abrupt and devastating. The soil surface loses its protection of living and dead leaves, and bare ground increases from nil to as much as 70% or 80%. On steep slopes, debris accumulating above a snow tussock finally overwhelms it, making the next tussock in the path of the debris more vulnerable (Fig. 10). Burned snow tussock stumps make insufficiently rapid growth to protect the soil surface. The effects of aridity induced by the bare surface, instability of the soil mantle, and possibly also reduced fertility of residual subsoil when erosion has removed the upper horizons, all combine still further to weaken the tussocks and to reduce the prospects of establishment of seedlings of any species.

Fig. 10.—Same locality as Fig. 5, showing snow tussock in process of being overwhelmed by stony debris. Scree in foreground. (Photo. J. D. Raeside, October, 1942).

As far as can be ascertained, no part of the high-altitude snow-tussock grassland has escaped fire except certain areas in western Southland, western Otago, and Fiordland, that are not in pastoral use. Consequently all the Kaikoura soils in pastoral use have eroded to some extent. It may be that all have also passed the point of no return, though not all are eroding at the same rate owing to local differences in management, climate, and situation. Only where an aggressive plant like *Celmisia spectabilis* has flourished is there some prospect of arresting the process of soil destruction.

Justification is claimed for burning as a regular practice on the grounds that (1) the accumulated fallen leaves make it difficult for musterers, shepherds, and sheep to move across steep hillsides; (2) the risk of accidental fires is great, since accumulations of inflammable litter burn very fiercely; (3) as the snow tussocks grow again and the canopy of leaves increases they become less suitable for pasturing sheep unless again opened by fire.

But if the tussocks are burnt, soil erosion becomes rapid and inevitable, because no plants are available to repopulate the ground bared by burning.

Taxonomy

The genus *Danthonia* includes several coarse tussocks, which are not always clearly distinguished from one another. Appendix I lists the principal New Zealand representatives and describes their characteristic features. Fig. 11 illustrates the nature of the differences.

The forms of *Danthonia flavescens* are of more than academic interest. Besides being morphologically distinct, they have different ecological requirements; each indicates some difference in site factors, and each is likely to respond differently to any kind of use or abuse. Each of the various forms has its own series of accompanying species and a careful survey of associated species might in fact be a good approach to differentiating snow-tussock forms. A beginning has been made by Barker (1953) where the species in snow-tussock grassland in one defined area are fully listed. In any other place the occurrence of a sharply different set of species, or even perhaps the lack of one very important constituent, like *Celmisia spectabilis* in this case, should arouse the suspicion that the snow tussock itself is of a different kind. It is to be expected that a few key species will be found to occur along with each form of snow tussock that is recognized. Haphazard species lists are of comparatively little value, since they usually include only the more conspicuous members, often plants of rocky outcrops that do not reflect the general conditions well. Another clue to the recognition of forms of *D. flavescens* may be found in the altitudinal sequence of communities. Snow-tussock grassland occurs above forest, or, in South Island, above fescue-tussock grassland on one of several soil types. The form of the *Danthonia* and the community it dominates may well differ in these cases. In North Island it is red tussock, never snow tussock, that occurs mingled with, or directly above, fescue-tussock grassland.

The snow tussock of high altitudes stands out fairly clearly from lowland red tussock on sour soils, both morphologically and ecologically. At intermediate levels there are extensive areas where the tall tussock is of indeterminate status, and intelligent treatment of these areas, and extension of any conclusions based on observations made there, depend on a clearer appreciation of their relationships.

The pattern of distribution of the various tall tussocks in South Island can emerge only from critical field observations supported by adequate specimens of what is typical for given areas.*

*Botany Division, Department of Scientific and Industrial Research, would be pleased to receive such specimens. It is particularly desirable that leaves should be collected right down to the crown of the plant, because the characters of the leaf sheaths are significant. The material taken from each single tussock (leaves with or without flower stems) should be folded upon itself to make a bundle about 14 in. long, and firmly tied round with its own leaves. Full details of locality and date of collection should accompany the specimen.

Fig. 11.—Some tall-tussock danthonias

(A) *D. flavescens* broad-leaved form.

(B) *D. flavescens* narrow-leaved form.

(C) *D. rigida.*

(D) *D. cunninghamii* upland forest form.

(x) Top of sheath, collar region, and lower part of blade.

(y) Inner surface of leaf blade at about middle.

(z) Portion of y enlarged.

All plants grown by Mr. A. P. Druce, at Upper Hutt. A, B, D, from Tararua Range; C, from Waiouru. (Photo. S. N. Beatus).

Life History of a Snow-tussock Plant

A full flowering of snow-tussock plants does not take place every year, e.g. 1954 was a year of abundant flowering. Barker observed profuse flowering of snow tussocks in February 1951 in that part of a block which had been burnt in September 1949; a clear line could be seen between freely flowering plants on the burnt, and sparsely flowering plants on the unburnt areas. The relationship between abundant flowering and seed-set is not known. There is no information on seed-set in general or about germination of seeds. Snow tussock, a large and long-lived plant, would possibly need few seed-setting years under optimum conditions to perpetuate itself.

Barker records that seedlings from seed buried by soil creep did not survive long. It is common observation that snow-tussock seedlings are rare. She also recorded snow-tussock spikelets that fell as a whole, which prevented seed from coming into direct contact with litter. Individual florets might more easily bury themselves than would spikelets. In other native grasses the failure of spikelets to break up into separate florets is often associated with lack of seed-set. A possible site for germination is somewhere in the base of existing plants. No data are available on this particular point, but it should not be overlooked in any investigation into life histories.

Plant Introduction

There have been no organized plant introduction trials in high-altitude snow-tussock grasslands; however, extensive over-sowing by runholders has been effected by the following means: spread from large quantities carried by pack saddle, broadcast from small quantities carried by men, organized throwing of seed on sheep's backs, and possibly sowing from the air. The results are negligible and have been costly.

As distinct from oversowing, one small sowing has been made at Lindis Pass (fenced plot), one at Mt. Edwards (fenced plot), and one at Blue Cliffs Station. About twenty species were sown, including *Agropyron* (7 species), *Festuca*, *Bromus*, *Elymus*, and *Eragrostis curvula*. No seedlings are recorded as being seen at infrequent inspections except at Mt. Edwards where the few plants that lived one season died the next. The failure of both native and exotic species points to the need for special-purpose plants for high-altitude snow-tussock grassland.

Economic Importance

The snow-tussock grassland is grazed in conjunction with fescue-tussock grassland of the Omarama, Alexandra, and Hurunui soils, and separate figures for carrying capacity are not readily obtainable. It is, however, used chiefly for summer grazing, and is regarded as of little value compared with the fescue-tussock grassland. In the primitive state it was regarded as unsuitable for pastoral use altogether. Estimates of carrying capacity of grazable country vary considerably and range from one sheep to 10 acres to one sheep to 20 acres; but these estimates are made on the assumption that the present deleterious practice of burning will be continued in order to keep the tussocks in a stunted and open state suitable for grazing. But as the tussocks recover from the effects of fire the capacity to carry sheep diminishes. Advances made by

various Catchment Boards in controlling fire have tended to reduce the average carrying capacity to less than one sheep to 15 acres. All attempts to introduce exotic pasture plants on the Kaikoura soils have failed, and soil conservation policies on this grassland depend on the extent to which the snow tussocks can be maintained. If they can be maintained, the carrying capacity will fall because a healthy snow-tussock community cannot be grazed; if they cannot be maintained, the carrying capacity will also fall because no plants have been found to take the place of the snow tussock, and failure to hold the snow tussock will accelerate erosion still further.

Unless very rapid advances are made in the introduction of forage plants on the Kaikoura soils, therefore, the present carrying capacities of the grassland must be regarded as an absolute maximum and liable to progressive reduction.

Not more than 300,000 is a tentative figure for the total numbers of sheep supported by the high-altitude snow-tussock grassland.

The conservation of the Kaikoura soils and the snow-tussock grassland takes precedence over that of all other montane soils and plant communities. The most active erosion at present taking place in the mountain catchments is that which is destroying the Kaikoura soils and providing the rocky waste aggrading the river beds in their lowland courses. Opening of the bulky snow-tussock community and the exposure of bare or nearly bare hillside also greatly increases the run-off and consequently increases flood risk. The nature and extent of flood-control works in the lower reaches of the rivers that drain the Southern Alps is therefore directly dependent on the stability of the Kaikoura soils and the well-being of the snow-tussock grassland. Irrespective of any improvements that can be effected in pasture management for the low-altitude fescue-tussock and silver-tussock grasslands, the battle for control of east-coast rivers will be won or lost in the high-altitude snow-tussock grassland.

The demands that soil conservation interests make on these soils are in sharp conflict with the requirements of the pastoralist, who cannot use for grazing a snow-tussock community that is in a healthy state.

Discussion

Since 1860 the high-altitude snow-tussock grassland has been deteriorating in a more obvious and spectacular manner than the remainder of the tussock grasslands (Fig. 12). This progressive destruction has not passed unnoticed. In 1865, Buchanan, referring to the tussock grasslands as a whole, emphasized that "nothing can show greater ignorance of grass conservation than the repeated burning of the pastures in arid districts." Petrie, also speaking generally, in 1912, believed that in parts of Central Otago and in the Mackenzie it "was not too late to conserve and nurse the failing pastures but a delay of a few years may make reclamation difficult or even impracticable for the last steps in the process of depletion are evidently rapid". He doubted whether fire should be permitted anywhere and certainly not in these districts. For another 30 years no action was taken to conserve the pastures, and much of the high-altitude snow-tussock grassland is now scree or nearly scree. Fire

Fig. 12.—Western slopes of Mt. Cheeseman, Craigieburn Range. The uppermost trees mark the position of the timberline as it was before the forest was destroyed by fire, *ca.* 1860. Above the old timberline the original vegetation was principally snow tussock passing upwards into alpine herbfields and high-altitude barren stonefields. Remnants, only, of this cover of snow tussock persist and the screes now extend down to a point well below the former timberline. But traces of tussock-grassland subsoils can still be found almost to the crest of the range at 5,000 to 6,000 ft. altitude.

Following the forest fires, the mountain slopes below the former timberline were occupied by fescue-tussock/silver-tussock grassland but these short-tussock grasslands have now also been largely destroyed with active gullying, sheet erosion, and scree formation. In part they have been overwhelmed by erosion debris from above. These slopes are still grazed, not only by sheep but also by considerable populations of deer and chamois. The only exotic plant species represented are catsear and sorrel. (Photo. N.Z. Forest Service, 1953).

is still used as an integral part of pastoral management, and in the territory administered by one Catchment Board permits were issued in 1953 for the burning of approximately 50 square miles of tussock grassland, some of which was high-altitude snow-tussock grassland.

The Commission on Southern Pastoral Lands (1920) state that deterioration can . . . "be defined as a reduction in palatability through the destruction of palatable species." It is . . . "only to be estimated accurately by one having a wide knowledge of species present and their relative food value." Deterioration (where bare ground predominates) was seen in all land districts visited by the Commission. The Commission recommended that snow tussock should be burnt only to provide tracks for sheep. In spite of this warning that the tussock grasslands could not be properly administered until this information was made available to land administrators and pastoralists, no action has been taken yet to provide it.

The Soil Conservation and Rivers Control Act became law in 1941, and under powers given to local Catchment Boards the use of fire in the snow-tussock grassland has been reduced but not eliminated. The Soil Conservation and Rivers Control Council has also set up a high-country research station at Tara Hills near Omarama which includes a considerable area of snow tussock.

Gibbs and Raeside in Bulletin 92 (D.S.I.R., 1945) mapped the soil and erosion pattern of the South Island high country and established that snow-tussock grassland dominated the Kaikoura soils, which, they emphasized, were the most severely eroded and the most susceptible to erosion of all high country soils. They also stressed the importance of fire and animals in promoting erosion.

The Royal Commission enquiring into the Sheep-Farming Industry in New Zealand (1949) recommended that Bulletin 92 should be replaced by an entirely revised edition, and stated that it "would not place erosion as a major factor of national consequence to the sheep industry". This latest Commission's report does not refer specifically to the snow-tussock grassland except in excerpts from the report of the 1920 Commission, fully endorsing the terms in which the condition of the tussock grasslands of South Island is there set out.

Spectacular erosion and Petrie's report of 1912 influenced the passing of a section of the Land Act of 1913, which, while permitting burning of some tussock grasslands, expressly prohibited the burning of snow tussock. It must be remembered, however, that Land Acts govern Crown Land only. The Land Act of 1924 permitted fire (with prior consent of Lands Department) in both fescue- and snow-tussock grasslands. The Act of 1948 is still substantially the same as the 1924 Act, i.e. it permits fire in both fescue- and snow-tussock grasslands, but authority for supervising has been handed to Catchment Boards and local Soil Conservation Committees whose jurisdiction is not confined to Crown Land only.

The concern about erosion in the first two decades of this century was one of the reasons for the setting up of the Commission on Southern Pastoral Lands of 1920. That Commission warned that "very little, perhaps nothing, is known for a certainty regarding the actual regrassing or improving of depleted and deteriorated lands, . . .". This is still true. At present no exotic or native plants are repopulating the bare ground; it may be that the gain from prolonged closing and protection of the snow-tussock grassland from grazing would be small, but it should slow down the rate of deterioration.

It will be clear, therefore, that there has been considerable conflict between the recommendations of various disinterested technical and scientific observers on the one hand and the actual administration of the snow-tussock grassland on the other. None of the suggestions and warnings have been followed by effective action.

Obviously there are still grievous gaps in knowledge, but the facts carry certain clear implications. They reinforce the warnings that have been repeated from time to time over the past 80 years and further emphasize that the soil-vegetation balance in the snow-tussock grassland is even more precarious than was previously thought.

Conclusions

The following conclusions are concerned strictly with the scientific aspects of the high-altitude snow-tussock grassland. Economic implications have not been discussed as they are considered to be outside the province of this Committee.

1. Changes in the soil mantle because of accelerated erosion and increased frost-induced movement have created a soil environment sufficiently unfavourable to the snow tussock to prevent its regeneration. The erosion of the soil has reduced its ability to provide the snow tussocks with a stable site, and adequate moisture and plant food.

2. There is evidence, moreover, to suggest that the snow-tussock grassland is, in the higher and drier parts of the high country at least, relict; where this is so, regeneration under any circumstances is unlikely. Seeding is intermittent and possibly ineffective, seedling snow tussocks are wanting, and replacement by other species is negligible. The period of survival of the snow-tussock communities may be determined by the life span of the present individuals. It is not known how long snow tussocks live in a favourable environment; but it is certain that erosion and an unfavourable environment will shorten their lives.

3. Snow-tussock grassland cannot withstand the biotic pressure of domestic and wild animals, and of fire.

4. The demands of soil conservation interests on the snow-tussock grasslands conflict sharply with the requirements of the pastoralist. The engineer who has to control floods and aggrading rivers, and the forester responsible for the forests that lie below and are being invaded by scree, require as nearly as possible a closed vegetation and a stable soil; but these cannot be obtained under pastoral use which requires an open, stunted snow-tussock community, with inevitable rapid soil creep and erosion.

5. Widespread invasion by exotic species has not taken place, nor has oversowing been successful.

6. Many of the fundamental problems in botany, pedology, and animal ecology have not yet been studied.

7. It may not be possible to save all the snow-tussock grassland. Some years must necessarily elapse before results from research can provide the basis for a programme of rehabilitation; but during this time the grassland would be steadily deteriorating. Every possible step should be taken to slow down the rate of deterioration so that the longest possible time is available to work out ways and means, and so that there is the largest possible area of soils still capable of being salvaged.

Consequently, the conclusion appears to be inescapable that there is no justification for retaining the high-altitude snow-tussock grassland in pastoral use until some method of revegetation is found.

It is recommended that all possible steps be taken to protect the high-altitude snow-tussock communities and soils from the known destructive agents, notably fire, sheep, cattle, and wild animals, and to implement a research programme covering the following topics:

Botany

(a) Taxonomy of the snow tussock *Danthonia flavescens*.

(b) Study of the individual snow tussock plant including such details as life-history, breeding system, seed-set, germination, and seedling survival.

(c) Ecology of snow-tussock communities, including further study of the climax-relict status.

(d) Experimental plant introduction.

Pedology.

(a) Extent and nature of disturbance by frost.

(b) Extent and significance of changes in soil flora and fauna induced by the opening of vegetation and erosion.

(c) Further study and subdivision of recognized soil units.

Animal Ecology

Foraging habits of all animals, especially sheep.

The runholder who depends in part for his livelihood on grazing the snow-tussock grasslands is faced with this dilemma: he cannot graze without burning, but if the grassland is burnt, both soil and vegetation will ultimately be destroyed.

APPENDIX I

TALL-TUSSOCK DANTHONIAS OF NEW ZEALAND

The following notes are offered as a guide to the forms or strains of snow tussock and should help in distinguishing these from other large coarse tussocks of the same genus.

These notes, assembled from information provided by V. D. Zotov and A. P. Druce of Botany Division, Department of Scientific and Industrial Research, cover all the large tussock *Danthonia* species that are at all adequately known, except for two or three that are confined to cliffs in North Island. The currently accepted name is given, and where necessary a reference also to the name used in Cheeseman's Manual of the New Zealand Flora (1925), or elsewhere where a description or figure is available.

Danthonia flavescens Hook. f.

Synonym: *D. raoulii* var. *flavescens* Hackel ex Cheeseman

This name covers what is commonly called snow tussock or snow grass as distinct from red tussock. The full range of its forms is incompletely known. In North Island most specimens can be placed in one of the following two groups, but in South Island the situation is undoubtedly much less simple. Features of this species are: glumes short; back of lemma hairy; awn flattened at base, usually twisted.

Broad-leaved form or forms: leaves $\frac{1}{4}$ to $\frac{1}{2}$ in. wide, flat, with some long hairs, nerves not very prominent; sheaths yellow, broad. This is known in North Island only from the Tararua Range (referred to in Zotov *et al.*, 1938, as *D. antarctica* Hook f. var. *flavescens*). In South Island, broad-leaved snow tussocks are common, but they may well include more than one form. Broad-leaved forms belong to high altitudes and do not occur below the bush-line (Fig. 11A).

Narrow-leaved form or forms: leaves narrower, channelled, not flat, without hairs, but more scabrid than in broad-leaved forms, less so than in var. *cheesemanii;* sheaths narrower, not definitely yellow. This is the only form of *D. flavescens* known in North Island north of the Tararua Range, where it is found also in exposed places (referred to in Zotov *et al.* (1938) as *D. antarctica* var. . . . (narrow leaved). There is evidence that this form hybridizes with *D. rigida.* This form occurs also in South Island, but there may be more than one narrow-leaved *D. flavescens* there. It may be found below the bush-line (Fig. 11B).

Low altitude forms. Snow tussock occurs at low altitudes, e.g., at Pigroot, Burke's Pass, Waihao Forks, Strath Taieri, etc. The status of these forms needs clarifying, but it is probable that they are distinct from any of the forms that are common at higher altitudes.

D. flavescens var. *hookeri* Zotov

Synonyms: *D. bromoides* Hook. f. of Cheeseman's Manual in part only; *Bromus antarcticus* Hook. f.; *D. antarctica* (Hook. f.) Hook f. (Fig. 102, Cockayne, 1928).

This name applies certainly to plants of Auckland Is. and Campbell Is. It is possible, however, that some mainland forms, e.g. from Ben Lomond and Arthur Pass, should also be referred here. (Cheeseman (1925) includes, with some doubt, these subantarctic plants with coastal ones of North Island, under the name of *D. bromoides.* This latter name should not be applied to any high-altitude plant in South Island.) The inflorescence is generally more compact than in *D. flavescens* itself; glumes are short, awns slightly flattened at the base and usually not twisted.

D. flavescens var. *cheesemanii* (Hackel ex Cheeseman) Zotov

Synonym: *D. raoulii* var. *cheesemanii* Hackel ex Cheeseman

This plant is known in the southern Tararua Range and the Aorangi Range (Haurangi Mts.) in Wellington Province, and in parts of Marlborough, usually below 2,500 ft. It is found in open forests, but differs from the other large forest *Danthonia* (discussed here under *D. cunninghamii*) in that the leaves are narrow, very green and scabrid with brown sheaths; the back of the lemma is not glabrous; the awns are flattened at the base and rarely twisted.

D. flavescens var. *elata* (Petrie) Zotov

Synonym: *D. oreophylla* var. *elata* Petrie

This is a smallish tussock, 12 to 18 in. tall, apparently confined to South Island high-rainfall areas. It approaches both *D. oreophylla* and narrow-leaved *D. flavescens* rather closely; from the former it differs in being taller, harsher, and stouter, and in having a larger panicle; from the latter in smaller size, fewer spikelets, and untwisted awns.

D. rigida Raoul

Synonym: *D. raoulii* Steudel (*D. raoulii* var. *rubra* Cockayne)

This name covers what is commonly known as red tussock in both North and South Islands. The type locality is Akaroa and it is still not completely certain that the specimen from there matches those common in other parts of the country.

Awn flattened at base and twisted; back of lemma hairy; leaves narrow, channelled and rolled, reddish, tapering gradually to a point; sheaths dark, especially inside, up to the collar (Fig. 11C).

Except for the variety *teretifolia* dealt with below, no distinct forms seem to have been recognized in this species, but it has been recorded as hybridizing with the narrow-leaved form of *D. flavescens* in North Island.

Druce (pers. comm.) states that in North Island this species is rather strictly confined to areas above 2,500 ft. that have been affected by ash showers; in the Tararua Range it is known only from one recently discovered area near the northern end; in the Ruahine Range it is almost confined to the northern parts, and it is not recorded from the Huiarau and Raukumara ranges.

In South Island this is a species of "sour" soil often at quite low levels but little is known of its occurrence at high altitudes there. In western Southland, Holloway (1949) quotes it as dominant in sub-climax grassland in areas where sub-continental *Nothofagus* forest should be expected.

D. rigida var. *teretifolia* (Petrie) Zotov

Synonym: *D. raoulii* var. *teretifolia* Petrie

A red tussock with wiry leaves that contract rather suddenly into a pungent point whereas those of *D. rigida* itself taper gradually. It was originally described from near Westport.

D. cunninghamii Hook f.

This name has been applied to at least two distinct forms, both with awns not flattened and back of lemma glabrous. One, which belongs to upland forests and may impinge on snow-tussock grasslands, has very hairy leaves with prominent nerves, pale sheaths and dark collars, and forms very large tussocks (Fig. 11D). Another, which may match the true *D. cunninghamii*, is a cliff plant of East Cape district; its leaves are not hairy, sheaths are purplish, scale leaves very big, and fans little flattened.

D. crassiuscula T. Kirk (Fig. 92, Cockayne, 1928)

This is a small stiff tussock less than two feet tall, with strongly involute leaves and small panicle with pubescent rachis and few spikelets. Awn flat and twisted at base.

D. oreophylla Petrie

A small soft tussock, awn not twisted.

APPENDIX II

Botanical and Common Names of Plants Mentioned in Text

Agrostis tenuis	Browntop
Anthoxanthum odoratum	Sweet vernal
Celmisia spectabilis	Cotton plant
Cerastium caespitosum	Perennial mouse-eared chickweed

Danthonia flavescens	Snow tussock, snow grass
Danthonia rigida	Red tussock
Festuca novae-zelandiae	Fescue tussock or hard tussock
Gaultheria depressa	Snow berry
Hieracium pilosella	Mouse-ear
Holcus lanatus	Yorkshire fog
Hypochaeris radicata	Catsear
Leucopogon fraseri	Patotara
Libocedrus bidwillii	Cedar, kawaka
Poa caespitosa	Silver tussock or yellow tussock
Poa colensoi	Blue tussock
Podocarpus hallii	Mountain totara
Podocarpus nivalis	Snow totara
Rumex acetosella	Sorrel
Taraxacum officinale	Dandelion
Trifolium dubium	Suckling clover
Trifolium repens	White clover

APPENDIX III

High Country Land Tenures

By B. E. Ussher, Department of Lands and Survey

By far the greatest bulk of the high country of Canterbury which is not freehold is held under Pastoral Run Licence or Small Grazing Run Lease. However, some country which was acquired under the Land for Settlements Acts, and which is purely pastoral, is held under Renewable Lease.

It would perhaps be interesting to trace the origin of the pastoral tenures from the commencement of settlement in Canterbury. Briefly, the history of early land settlement in this Province commences with the Land Regulations contained in the charter of the Canterbury Association of 1849. Those regulations bound the early settlers of 1850. The Association's idea was to provide large estates (at a sale price of £3 0s. 0d. per acre), for monied classes and thus form an aristocracy; the working men were to become the yeomen and the peasant class. This idea did not work in practice and thus did not result in settlement of the land. Godley saw how things were shaping and changed the Regulations in 1851, providing for runs of from 5,000 to 50,000 acres to be taken up by anybody. Application could be made at the nearest Land Office by any person who may have seen a likely piece of country; he described the land, usually by defining its natural boundaries, and, if there were no prior applications, he was usually granted the run by the Waste Lands Board. The run had to be stocked within six months at the rate of one sheep to 20 acres or one cow to 120 acres. The rent was ¼d. per acre for the first two years, ½d. for the next two, and ¾d. thereafter. The terms of the Licence provided for forfeiture for non-fulfilment of conditions. The licensee, or anyone else, could buy all or part of the run at any time and also had pre-emptive rights to freehold certain areas, mostly of 50 acres, adjoining each hut and 38½ chains of fencing he erected. These pre-emptive rights, of course, are the main reason why in many of our Canterbury runs all the best land is freehold, and are thus the reasons for the grid-ironing which is so apparent today in the high country.

The new Regulations immediately resulted in a great scramble for runs; by 1855 all the plains and foothills had been taken up, and by 1865 every acre to the foot of the backbone range had been selected.

There were then about 600 runs all over Canterbury (including the plains), grouped into 250 stations.

The early settlers laboured under considerable difficulties establishing homesteads, etc., and until wire fences were first introduced in 1860 shepherds had to tend the flocks constantly.

Provincial Government was abolished in 1876 and the N.Z. Government took over administration of the Canterbury runs, and allowed land to be taken up under the old terms until 1880. The Land Act of 1877 provided for the revaluation of runs according to capacity and situation, and allowed tenants to hold for 10 years at the rents fixed on revaluation. Pre-emptive rights were abolished but the licensee was permitted to freehold up to 320 acres for a homestead site. The area of a run was supposed to be limited to land sufficient for 5,000 sheep or 1,000 head of cattle, and the pasturage licence entitled the holder to the exclusive right of pasturage only. The licence was subject to termination on 12 months' notice.

The old pasturage licences first expired in 1890, and, as required by the Land Act 1885, the runs were offered at auction for terms varying from 7 to 21 years according to when, if ever, they were wanted for closer settlement. The limit of carrying capacity was increased to 20,000 sheep or 4,000 cattle and the area that could be purchased was reduced to 150 acres. At this time a good deal of land was taken from the runs for closer settlement but most of the old tenants got their runs back at auction.

The old stations on the plains began to disappear during the 1880s. The introduction of wire fences, water-races, and, to a large extent, meat freeezing, naturally encouraged closer settlement and cultivation.

The bulk of the Pastoral Licences granted in 1890 expired by 1909–11, and, some time before expiry, were reported on by Land Classification Commissioners provided for under the Land Acts of 1892 and 1908. Runs were required to be classified according to whether they could (1) not be economically worked with less than 5,000 sheep and (2) be used for pastoral–agricultural purposes but were suitable for subdivision in areas not exceeding 5,000 acres. Except in extraordinary circumstances the maximum carrying capacity of any run to be offered could not exceed 20,000 sheep or 4,000 cattle. As a result of the Classification Commissioners' reports, a considerable amount of subdivision took place.

The Land Act 1908 still did not provide a right of renewal for Pastoral Licences and the Government's decision to continue the offering of runs at auction for 21-year terms roused great criticism mainly on the grounds that this debarred the small man without much capital from acquiring a run. According to reports at the time, it let in only the men with "long purses". There was a land hunger in 1909 and in many cases fantastic rents were bid at auction and large goodwills paid for the transfer of licences—in many cases the rents were more than double the upsets. Another point was that the owner of low country and adjoining freeholds often had a stranglehold on the runs, making closer settlement impossible. However, the Land Amendment Acts of 1912

and later years improved the conditions of occupation of pastoral land and provided for licences of up to 35 years, and also provided for the extension, if the licensees wished, of existing licences for a further 14 years provided the land was unsuitable for subdivision. A right of renewal was also granted in that, if the land was deemed unsuitable for subdivision, and was again to be let, the licensee, on expiry of his existing licence, could obtain a new licence for a further term without competition; if the run was suitable for subdivision the existing licensee had a prior right to such one of the subdivisions as he chose. Any licensee holding a Pastoral Run of under 20,000 acres could exchange to a Small Grazing Run lease. Moreover, the licensee, by the Amending Act of 1921/22 had the right to freehold his run provided the area so freeholded was not greater than was sufficient for the maintenance of himself and his family, and provided his licence was not less than 14 years. New runs could by now be offered for selection at auction or ballot at fixed rent.

The Land Act 1924 largely embodied the provisions of the previous Act and amendments regarding the maximum capacity, etc. Licensees had right of renewal of run, or, if subdivided, of one subdivision. The exorbitant rents bid at auction and high goodwills paids in the past had resulted in overstocking with its consequent ill effects on the land, and the former insecurity of tenure had not encouraged good husbandry. Many of the rents for Pastoral Runs were too high, and in the 1930s great use was made of Section 277 of the Land Act 1924. This section enabled a licensee to surrender his licence and obtain a new licence at a revised rental as recommended by a Special Valuation Committee. About 1940, good husbandry clauses were introduced into all new pastoral licences, limiting the stock to be wintered, and making other provisions thought to be beneficial to the run country.

The Land Act 1948 aims at producing the ideal type of tenure for pastoral country and provides that all land held under pastoral licence is to be classified so that, on renewal of the old licences, one of the following types of tenure is to be granted:

(1) *Pastoral Lease:* Briefly, this is a lease for a term of 33 years and is perpetually renewable, as of right, for further 33 year terms. If the run is being well managed and is not required for regrouping purposes, the Land Settlement Board will, as a general rule, grant a pastoral lease on the expiry of the old licence.

(2) *Pastoral Occupation Licence:* These licences can be issued for any term up to 21 years and are not renewable as of right. The decision whether to grant a Pastoral Occupation Licence is largely dependent upon factors such as the uncertainty of the future usefulness of the run, its availability for any required regrouping and, above all, liability to soil erosion and reversion.

In general, however, where it is evident that good husbandry is being exercised and that the land can safely be leased for a long period, the Land Settlement Board will, in most cases, be prepared to grant a Pastoral Lease.

Pastoral Leases and Pastoral Occupation Licences contain good husbandry clauses limiting the stock to be carried and also contain such other clauses as the Board may think fit. In each case the rents are

based on carrying capacity. The Board is most anxious to promote and encourage good husbandry on the pastoral country and, in several cases, had rewarded past good husbandry, usually by fixing the rent on a lower flock than is actually being carried on the run.

As a point of interest, there were 143 pastoral runs in 1905 and only 115 today.

Small Grazing Runs

The Land Act 1885 contained the main provisions regarding pastoral licences and also brought into existence the Small Grazing Runs tenure under which pastoral land not exceeding 5,000 acres could be leased (at auction) for a 21 year term at an upset rent of 2½% of the rental value fixed by the Land Board. The lessee had to reside for six years and had a right of renewal if it were determined that the run, or part, should again be let—the renewal rent to be 2½%. The Small Grazing Run lease entitled the lessee to pasturage and crops but also imposed certain improvement conditions on the lessee. There was no right of freehold. In a few years the advantages of this tenure became manifest and resulted in settlement of, and improvement to, rough broken bush country. With such a low rental basis the settler was free to employ his capital in stocking and improving the land. No person with more than 1,000 acres of land could apply for a Small Grazing Run. The Amending Act of 1887 increased the area limitation of a run to 20,000 acres. The Land Act 1892 did away with offering Small Grazing Runs at auction, and provided for offering at a fixed rent—still on a 2½% basis. The lessee was given a right of renewal over the whole run.

The Amending Act of 1912 altered rights of renewal to provide that if the run were suitable for subdivision, the lessee was entitled to a renewal over one subdivision only. The rental basis was altered to "such yearly rent as the Board may fix", and could not be less than 2½%. The 1913 Amending Act gave the right to freehold up to 5,000 acres and this right was slightly altered by the 1922 Amending Act which gave right to freehold the whole run if the balance over the 5,000 acres was unsuitable as a separate holding. The Land Act 1948 has done away with the Small Grazing Runs tenure and provides that, on renewal, an ordinary renewable lease be granted over the whole run at 4½% rent on unimproved value. Small Grazing Run lessees now have ordinary rights of freehold of the whole run.

APPENDIX IV

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PASTURE ESTABLISHMENT STUDIES

IV. A COMPARISON OF MIXTURES CONTAINING SHORT-ROTATION RYEGRASS, PERENNIAL RYEGRASS, OR BOTH, AS THE GRASS COMPONENT

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(Received for publication, 12 August 1954)

Summary

A comparison was made of the establishment of mixtures containing short-rotation ryegrass, perennial ryegrass, or both, as the grass component, with red and white clovers as the legume component. The grass component was sown at two rates, 15 lb. and 40 lb. per acre, whereas the clovers were sown at constant rates. Herbage yields were measured and clover survival was determined over a period of 8 months from sowing.

Short-rotation ryegrass was more aggressive than perennial ryegrass during the establishment phase. As a result, decreased growth of clovers but better suppression of weed growth was obtained in the short-rotation ryegrass sowings.

The effects of seeding rate of short-rotation ryegrass on the establishment and development of sown species were similar to those reported in previous parts of this series, but for perennial ryegrass the effects were less marked.

The pastures establishing from light sowings of short-rotation ryegrass were similar in many respects during development to those of heavy sowings of perennial ryegrass. This applied particularly to the late autumn, winter, and early spring growth of both pastures. It is concluded that during this period the aggressiveness of the ryegrass component in both these sowings was similar.

The practical applications of the results from Parts I–IV of this series are discussed.

Introduction

Perennial ryegrass (*Lolium perenne*) has for many years been the major constituent of pasture seeds mixtures in New Zealand, and the almost universally recommended rate was 40 lb. per acre. During the early stages of the introduction of short-rotation ryegrass (*L. perenne* × *L. multiflorum*) the same sowing rate was recommended for mixed sowings of both ryegrasses. It was soon obvious, however, that in sowings where the new hybrid formed a substantial part of the mixture, poor establishment of sown species often resulted. The major cause of failure was suppression of the slower-growing legumes. In previous parts of this series (Brougham 1954 a and b), the interaction between species, in simple mixtures of short-rotation ryegrass with red and white clovers, was studied and more successful establishment of clovers was obtained where lower seeding rates of short-rotation ryegrass were used.

The present paper compares mixtures containing the two ryegrasses, both separately and in association, at high and low rates of seeding.

Experimental Design and Procedure

The field was ploughed out of spaced plants of ryegrass spp. on 29 March 1951, and was of relatively high fertility (c.f. previous parts). The spaced plants had been fertilized with superphosphate and sulphate

of ammonia and grazed by sheep. After ploughing and seed-bed preparation the area was topdressed with 1 ton of lime and 3 cwt. of superphosphate per acre. On 3 April 1951, plots were sown to the mixtures shown in Table 1.

TABLE 1. VIABLE SEED SOWN PER ACRE (LB.)

Species Sown	Mixture					
	1	2	3	4	5	6
Short-rotation ryegrass	40	—	20	7½	15	—
Perennial ryegrass	—	40	20	7½	—	15
Broad red clover	4	4	4	4	4	4
White clover	3	3	3	3	3	3
Total	47	47	47	22	22	22

All seeds sown were of certified pedigree class.

The plots were hand-sown, and following this were hand-raked to cover the seed.

In addition to the seeds mixture treatments, the following nitrogen treatments were applied at sowing.

(1) No nitrogen.

(2) Nitrochalk equivalent to 47 lb. N per acre (3 cwt. nitrochalk per acre).

(3) Sulphate of ammonia equivalent to 47 lb. N per acre (2 cwt. sulphate of ammonia per acre).

The experimental layout was of a split-plot design, with 4 replications of the 3 nitrogen treatments as the main plot treatments, and the six seeds mixtures as sub-plots (18 ft. × 6 ft.) within the main plot treatments. Each block of treatments was surrounded by 6-ft. headlands, in lawn. The blocks were fenced separately but were grazed at the same time for each grazing. All grazings took place when the average height of herbage was 3 to 4 in. The techniques used for cutting, sampling, and grazing were the same as those used in the experiment reported in Part I (Brougham 1954a).

Botanical analyses of individual plots were made only at certain cuttings. In all other cases a bulked sample of replicate plots was analysed, so that separate botanical analyses of each of the 18 treatments were obtained.

Seedling counts were made at emergence, and populations of clover plants were determined at intervals during the experiment. A quadrat 3 ft. × 4 in. was used for these counts, and sequential random samples, sufficient to give the required accuracy, were taken.

The experiment was concluded on 3 December 1951.

RESULTS

The detailed results obtained for the nitrogen comparisons are not presented. Apart from slight initial increases in green weight of

ryegrass and decreases in dry-matter percentages, no significant effects of added nitrogen at sowing were recorded throughout the experiment. Consequently, all analyses of variance were performed for a lay-out of six seeds mixture treatments in twelve blocks. This was a valid procedure, as the original layout was a split-plot one, with the nitrogen treatments as the main treatments.

Total Herbage Production and Species Yields

Total herbage, ryegrass, and unsown species yields are presented graphically in Fig. 1, 2, and 3 respectively. These figures show yields as average daily dry-matter increment, and each point on the graphs was obtained by dividing the weight of herbage produced at each measurement by the number of days between successive measurements. They have been plotted as the mid-points of the sampling period. It is realized that this procedure produces an arbitary rate-of-growth figure only, and assumes that rate of pasture growth between grazings is constant. However, the procedure is used here for comparative purposes only. It should also be noted that the technique used for measurements of herbage yield did not account for growth during the grazing period of 2 to 5 days. The results of eight measurements are shown, the first commencing on 3 April 1951 and the last concluding on 3 December 1951.

Only total herbage yields were analysed statistically, and the results of the analyses of variance have been incorporated in Fig. 1. The difference required for significance at the 5% level of probability is shown for each measurement. Analyses of variance of yields of ryegrass and unsown species were not performed as botanical analyses of separate species were not obtained for all plots at each grazing. Conclusions drawn from species yield data have therefore been deduced with reference to total yield differences and botanical analyses.

Clover yield data are not presented. Instead, the competitive effects of the ryegrass component on clover development are illustrated by clover plant survival counts, as shown in Table 2.

Yields are expressed throughout as pounds of dry matter per acre.

Total Herbage Yields

Fig. 1 shows herbage yields obtained from the six seeds mixtures for the eight periods of measurement 3 April to 3 December 1951.

From Fig. 1, the following features gave statistical significance at the 5% level or higher.

Comparison of the Ryegrass Components. For the first four cuts, more growth was obtained from short-rotation ryegrass mixtures. This applied equally at both sowing rates. After mid-September, however, the perennial ryegrass mixtures outyielded short-rotation ryegrass sown at the same rate.

Seeding Rate. Growth obtained during the first four to five months from sowing was higher from the heavy sowings. This applied for both ryegrasses, although the effect was more pronounced for the short-rotation ryegrass. Over the next three to four months, no significant differences in total growth were apparent, except for the last measurement when all lighter sowings outyielded comparable heavy sowings.

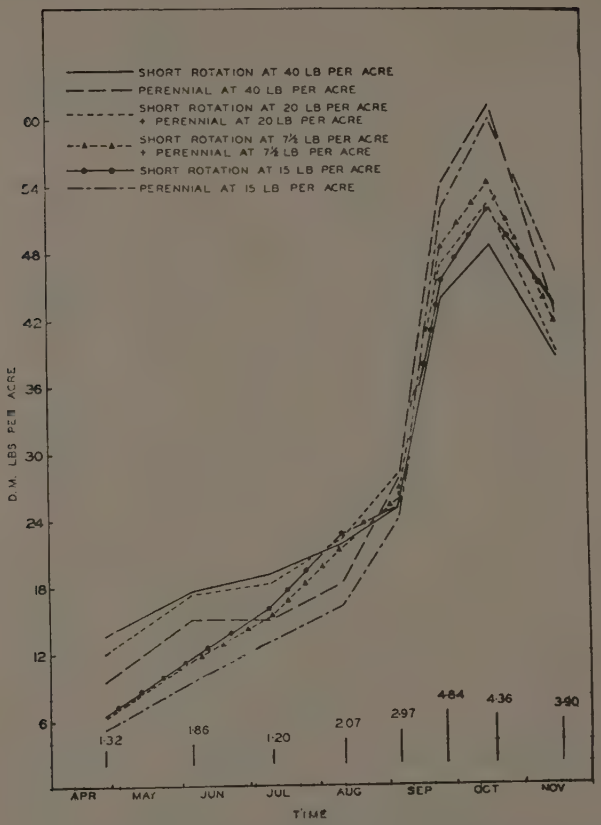

Fig. 1.—Total herbage production (as dry-matter increment per day) from the six treatments for the eight periods of measurement. Also shown as vertical bars are the values of d.05 for each measurement.

Other Comparisons. During the first five months, total yields obtained from the light sowings of short-rotation ryegrass and the heavy sowings of perennial ryegrass were approximately equal.

Ryegrass Yields

Fig. 2 shows ryegrass yields obtained from the six seeds mixtures for the eight periods of measurements, 3 April to 3 December 1951.

The following deductions are made from Fig. 2:

Comparison of the Ryegrass Components. For the first four measurements, ryegrass yields in the short-rotation ryegrass sowings were greater than those from the comparable perennial ryegrass sowings. A reversal then commenced at the higher sowing rate and by September the perennial ryegrass sowings outyielded the short-rotation ryegrass sowings. At the lighter rate, however, differences in yields between strains of ryegrass during this period were small.

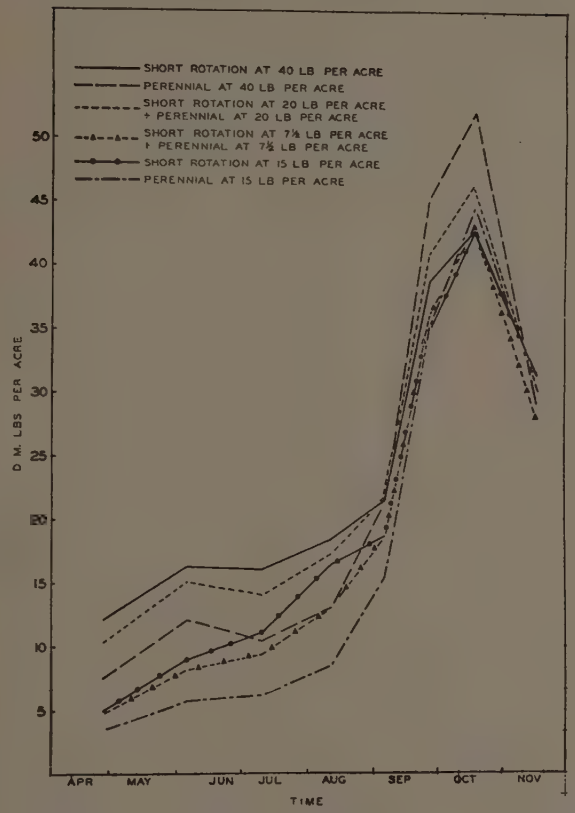

Fig. 2.—Ryegrass yields (as dry-matter increment per day) from the six treatments for the eight periods of measurement.

Seeding Rate. From the time of sowing to the end of August, ryegrass yields from the high seeding rates were greater than those from light seeding rates. This applied for both ryegrasses. Following this, ryegrass yields obtained from the short-rotation ryegrass sowings did not differ appreciably, whereas for the perennial ryegrass sowings the heavy rate continued to outyield the light rate until the last measurement. Yields were then approximately equal.

Other Comparisons. Total ryegrass yields obtained from the light sowings of short-rotation ryegrass for the first five months were much the same as those obtained from the heavy sowings of perennial ryegrass. Following this, however, the perennial ryegrass sowings gave increased yields.

Yields Obtained from Unsown Species

Fig. 3 shows yields of unsown species, obtained from the six seeds mixtures treatments for the eight periods of measurement, 3 April to 3 December 1951.

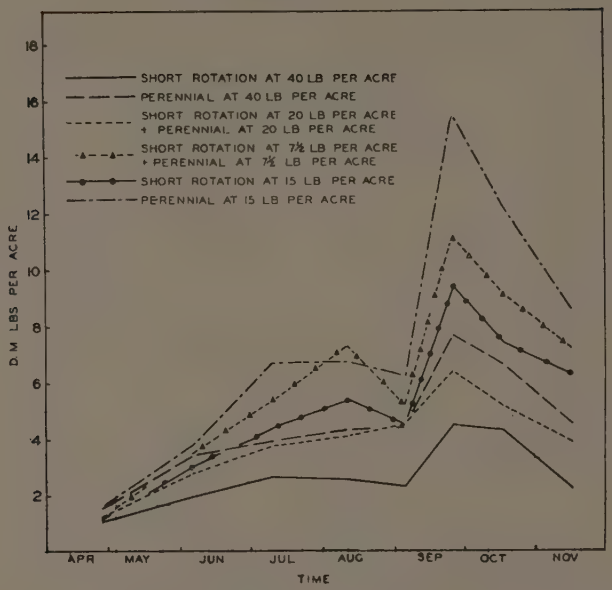

Fig. 3.—Yields of unsown species (as dry-matter increment per day) from the six treatments for the eight periods of measurement.

From Fig. 3 the following deductions are made:

Comparison of the Ryegrass Component. Initially there was little difference in growth obtained from unsown species in the various treatments. However, from June through to the final measurement, growth of unsown species was greater in the perennial ryegrass sowings.

Seeding Rate. Throughout the full period of the experiment, yields of unsown species were highest in the light seeding rate treatments.

Other Comparisons. The least difference in growth of unsown species was between the light sowings of short-rotation ryegrass and the heavy sowings of perennial ryegrass.

Percentage Emergence and Plant Survival of Clovers

Percentage emergence of clover seedlings did not differ significantly. Over all treatments, 22 viable seeds of red clover and 46 viable seeds of white clover were sown per sq. ft., and the percentage emergence of both was 65.5.

The results presented in Table 2 show numbers of red and white clover plants per square foot surviving under the various treatments at two dates. The results of the analysis of variance are also included.

Deductions from Table 2 are:

Red Clover. At the first count, the number of surviving clover plants in the light sowings were significantly higher (1% level) than in the heavy sowings. Within these two groups, however, differences were

TABLE 2. NUMBER OF SURVIVING RED AND WHITE CLOVER PLANTS
(number of plants per sq. ft.)

Date sown 3/4/51

	Mixture	High-rate Sowings			Low-rate Sowings			Results of F test	d.05 (where F sig.)
		Short-Rotation	Perennial	Short-Rotation + Perennial	Short-Rotation + Perennial	Short-Rotation	Perennial		
Red Clover	Number of Plants Surviving on 17/7/51	6.8	6.5	6.6	8.8	8.7	9.5	**	1.81
	Number of Plants Surviving on 13/9/51	5.5	7.0	5.0	6.2	6.5	6.5	*	1.33
White Clover	Number of Plants Surviving on 17/7/51	14.7	17.7	17.6	20.1	21.2	22.1	**	2.51
	Number of Plants Surviving on 13/9/51	13.4	16.5	13.1	18.8	18.0	18.3	**	2.01

d.05 difference required for significance at the 5% level of probability.
** differences significant at the 1% level of probability.
* differences significant at the 5% level of probability.

not significant. For the second count, the seeding rate comparison did not reach significance, although there were significant differences (5% level) between individual treatment means.

White Clover. The numbers of clover plants surviving in the heavy sowings were significantly lower (1% level) than in the light sowings. No significant differences were obtained between treatments at the low seeding rate, but at the high seeding rate the number of plants surviving in the short-rotation ryegrass sowings were significantly lower than the other two treatments in this group.

At the second count, the mixture containing short-rotation ryegrass at the high rate of sowing and those containing both ryegrasses at this rate, had significantly fewer (1% level) plants surviving than the mixtures at the low rate and also the high rate sowings of perennial ryegrass.

DISCUSSION

The results clearly demonstrate that, when sown in the autumn, short-rotation ryegrass grows much more vigorously than perennial ryegrass during the first four or five months, a reflection of its faster tillering rate (Mitchell 1953) and better winter growth (Corkill 1949). This difference between strains is illustrated well by the close similarity in yields of both sown and unsown species in the sowings of 15 lb. per acre of short-rotation ryegrass and of 40 lb. per acre of perennial ryegrass.

In previous papers of this series (Brougham 1954 a, b) an inverse relationship has been reported between yields of grass in late autumn and winter and survival of clover plants. This is similarly demonstrated in the present paper when a comparison is made between sowings of short-rotation ryegrass at 15 lb. per acre and at 40 lb. per acre, and perennial ryegrass at 40 lb. per acre. The approximate ratios of grass yields over the first five months (4 measurements) are 7: 11: 8 and the corresponding ratios of clover plant survival at 24 weeks are 25: 19: 24. As has been previously stated, these results are adequately explained in terms of competition for light between grasses and clovers. A similar explanation also applies to growth of weed species in the establishing pastures.

Competition between the two ryegrasses is also apparent from the results. Measured either in terms of grass yields or of clover survival, the mixed ryegrass sowings show greater similarity to short-rotation ryegrass sowings than to perennial ryegrass sowings.

Inter-species competition for light and intra-species competition for nitrogen were regarded as being the main determinants of yield and botanical composition in previous papers. In this investigation it is suggested that in the last three months of the trial the higher yields of perennial ryegrass, particularly at the heavier seeding rate, is a reflection of competition for nitrogen. The highest-yielding treatment during late autumn and winter developed from the heavy sowings of short-rotation ryegrass, and it is probable, as suggested in Part III (Brougham 1954b), that the greatest losses of original soil nitrogen would occur in this treatment. It is also probable that the contribution by clovers to soil nitrogen supplies at this stage in the development of these pastures was negligible. Under these conditions, therefore, the lower winter yielding treatments would outyield the other treatments in the spring months.

General Discussion

Pastures differ from practically all other crops of economic importance in that they are invariably associations of plants with different growth habits and different competitive abilities. Hence, in studies of pastures, not only is an understanding of intra-species competition involved, as in crops, but the added complexity of inter-species competition is also present. This poses problems peculiar to pastures during the establishment phase, since in many cases the relative competitive capacity of the plants in the association changes markedly as the pasture progresses from the juvenile to the established phase.

In the investigations reported in this and previous papers in this series, simple mixtures have been studied, and the competitive capacities of the various components of the mixtures have been established. These results show agreement with those obtained by Stapledon *et al.* (1927), with barley as the most aggressive species, followed by short-rotation ryegrass, then perennial ryegrass. The clovers are the least aggressive. Consequently the problem has been considered as primarily one of ensuring that the slower-growing clovers establish well and are not overgrown by dominant grass growth, since poor clover content leads to nitrogen starvation of the grasses as soon as available soil nitrogen is depleted (Sears 1953a, b). To this end, variations in grass seeding rate and in early grazing management, and the effect of a cereal cover crop, have

been studied. The results obtained form a coherent picture of wide applicability. Concurrently, quantitative information has been obtained on the effect of these various factors on the total productivity of autumn-sown pastures during the following winter and spring.

The degree to which clover plants will grow successfully in autumn sowings of simple mixtures of grasses and legumes is obviously a function of grass seeding-rate. Results obtained in Part I (Brougham 1954a) and those obtained by other workers (Donald 1951; Williams 1947), show quite definitely that the intensity of both inter- and intra-species competition increases with increase in seeding rate. This assumes of course that initially other factors, such as soil medium, nutrient level, and grazing management, are the same. Consequently, the development of individual seedlings of grasses and clovers is restricted first at the higher seeding rates and later at the lowest seeding rates by the operation of this competition. In the early stages of development, competition both between and within species is for light, and at the higher seeding rates (40 to 60 lb. of short-rotation ryegrass per acre) is sufficiently intense to cause considerable death of clover seedlings. Competition between the functioning ryegrass tillers for available soil nitrogen then follows, and subsequent growth is limited by this factor. In the experiment reported in Part I, this occurred in early spring. When excessive competition for light does not occur in the initial stages of development, however, as in the lighter seeding rates (10 to 15 lb. of short-rotation ryegrass per acre), clover plants establish successfully. The nitrogen status of these associations is then assured at an early date by vigorous early growth of clover.

The height of herbage at defoliation affects inter-species competition in the same way as grass seeding rate. The results obtained in Part II (Brougham 1954a) show that, where pastures are allowed to grow to an advanced height before grazing, reduced vigour and higher mortality of seedling clovers ensue. Where aggressive grass growth is controlled, however, inter-species competition for light is lessened and more clover seedlings survive. The potential for spring growth is then increased.

A secondary aim in the establishment of relatively long-term pastures is the production of feed for periods of feed shortage during the establishment phase. The late autumn, winter, and early spring are periods of feed shortage (McMeekan 1943), and the results obtained from this series of experiments show that grass production in late autumn and winter can be increased by heavy grass sowings, by the inclusion of cereals in the mixture, and by long intervals between grazings. However, these measures all militate against clover establishment, and also lower the supply of available soil nitrogen to a stage where the later productivity of the pasture is considerably reduced. These effects of heavy grass crops in the first winter will obviously be greatest on heavy land which pugs easily. It is suggested, therefore, that where winter feed is a primary consideration, better results would be obtained by sowing a temporary pasture or a crop such as a cereal, followed by a spring sowing of a more permanent mixture of grass and clover.

Grass species are often sown at heavy rates in order to suppress weeds. In the early stages of pasture development, this effect appears satisfactory, but clover seedlings are also suppressed together with the weed seedlings, to the detriment of later production. Other methods of

weed control such as fallowing before sowing, or spraying after the establishment phase, are preferable.

A significant feature of the results obtained from all experiments is that relating to soil nutrient levels, and in particular to soil nitrogen levels. The areas involved in all experiments, except that for the experiment reported in Part II, were considered to be of reasonably high fertility. It is probable also that in all developing associations the amount of nitrogen fixed by the establishing clover plants before the spring was negligible. The results suggest, therefore, that the amount of soil nitrogen available at sowing, together with that released by soil bacteria during the late autumn and winter, was sufficient to meet the requirements of good grass growth until the end of winter, after which grass growth was limited by this factor. The time of sowing in these experiments corresponded to the average sowing date in the district, i.e., towards the end of March. Consequently, the establishing clover plants had not reached an advanced stage of development before the onset of the colder temperatures. The significance of this on nitrogen fixation, and hence on the development of the pastures, is obvious. Similar work to that reported in this series is therefore required but with the added variable of time of sowing included. Of particular interest also would be a study of the effect of artificial nitrogen, applied at various stages in the development of pastures. The requirements of other grass species during the establishment phase also need elucidation.

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CUTTING TECHNIQUES IN GRASSLAND EXPERIMENTS

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Summary

Five different cutting techniques that have been used with the "frame" or "enclosure" method of measuring pasture production were compared in a technique trial designed to test their efficiency in measuring grass growth. From considerations of the amount of field work, the size of errors associated with the data, and the accuracy in estimating growth produced it was concluded that the "standard" method of the Extension Division, Department of Agriculture, using a pre-trimming cut and a mower to cut the herbage, was to be preferred for most types of investigation.

Introduction

Measurement of herbage production in grassland experiments is less simple than measurement of grain yields in cereal trials. With grain yields there is a single true value for each plot yield and the question of the best field technique to ascertain this true value, or at least a good approximation of it, depends on practical and statistical considerations. With grassland yields, however, records of production are continuous, and the techniques used in measuring this have an important effect on the values that are obtained. There is no absolute or "true" production figure of the herbage production over a period from any particular sward; the yield recorded depends on the method of cutting, the height of cutting, the frequency of cutting, the grazing management used (if any), and the experimental technique adopted. Different pasture species react in different ways to these variables.

These matters, fortunately, do not necessarily apply with equal force when treatment comparisons are made, particularly if these treatments do not exert in themselves marked effects on the species composition of the pasture. Many fertilizer comparisons fall into this category. The determination of the total pasture production of a sward over a period is affected to a much greater extent by the cutting and experimental technique adopted. The best cutting technique is that which causes least departure from what is accepted as "normal" grazing management.

The "frame" or "enclosure" technique[1] probably meets the requirements of measuring production with the least possible upset of normal grazing management. In this method each experimental plot is large enough to permit such management, and small movable cages or frames are used to protect areas within each field from grazing for the obtaining of herbage production data. Different workers have adopted different methods of moving the frames, different methods of removing herbage within the frames, and different means of estimating the pasture production. The trial to be described compared five of these cutting techniques for their efficiency in terms of sampling error, the figures they gave for total herbage production, and the pasture species that were represented in the weighed material cut by each technique.

Description of the Techniques Compared

A. "Standard" Method of the Extension Division

A motor-mower is used to cut growth to a uniform height. The height of pasture when cut is normally that which would be considered slightly long for sheep grazing, namely 3 to 6 in. high. After grazing is finished in each experimental field, cutting is delayed until all the pasture outside the frames has recovered above the height of cutting ($\frac{1}{2}$ to 1 in.). This is usually 2 to 4 days.

The herbage inside the frames is then mown and weighed, and at the same time other areas in the paddock are trimmed to an even height with the mower and frames placed thereon. A "trimming" cut always precedes a "mowing and weighing" cut, and growth is measured from the uniform mown height left after trimming.

B. "Difference" Method of the Extension Division

Trimming of areas for placing of frames in new positions and the taking of weighing cuts in this case is done directly grazing finishes. Trimming cuts are weighed. Herbage consumption during the grazing period is measured by the difference between production as measured within the frames (where the grass is protected from grazing) and that outside the frames (the trimming cuts) which has been subject to grazing. The total pasture production is measured by the growth within the frames. It is obvious that if part or all of the grazed pasture is shorter than the height left after mowing, this method will under-estimate pasture production and consumption. To work satisfactorily, the grass must be mown as close to the ground as possible, and the grazing intensity must never be such as to defoliate the pasture below the height of mowing.

C. "Difference" Technique: Australian Method[2]

This is similar in some respects to B above but hand shears or clippers are used to cut growth to ground level and frames are not placed on previously trimmed areas. After grazing finishes, the following cuts are made:

(1) Herbage within the frames, which are then replaced on new sites.

(2) "Open cuts" in the field on areas which have been grazed. The positions for these open cuts are found at random and the frames are placed on uncut areas adjacent to these open cuts.

Herbage production is estimated from the amount cut from within the frames less that from the open cuts made *when the frames were placed*. These open cuts estimate the amount of herbage on the frame areas when the frames are placed in their new positions at the start of the measurement period. Herbage consumption is measured by the amount cut within the frames (the amount available to the grazing animal) less that of the open cut *made on the same day* (the amount left after grazing).

D. "Grazing Estimation" Method[2]

Herbage is removed for weighing from within the frames by hand-cutting or "plucking" to copy the irregular defoliation pattern of the grazing animals. When this herbage is removed, the growth remaining

within the frames should not be distinguishable from that outside the frames. The frames can therefore be placed in new positions without the need for prior trimming cuts. This hand-cutting is done as soon as possible after grazing finishes.

E. "Rate of Growth" Technique

This is essentially similar to Method A except that regular intervals are maintained between cuts in order that growth during low-production periods may be measured. Two frames are required for each weighing cut in order that the method may be operated independently of grazing; one of these frames protects herbage from grazing until it is above mowing height and can be trimmed-up in preparation for a "mowing and weighing" cut.

DESCRIPTION OF THE EXPERIMENT

A simple trial was laid down at the Marton Experimental Area[4] in 1941, in three ½-acre fields in which the following seeds mixtures were sown:

1. Certified pedigree perennial ryegrass, 40 lb. per acre; Certified pedigree white clover, 3 lb. per acre.
2. Short-rotation ryegrass (seed supplied by Grasslands Division, Department of Scientific and Industrial Research) 20 lb. per acre; Certified pedigree perennial ryegrass, 20 lb. per acre; Certified pedigree white clover, 3 lb. per acre.
3. Short-rotation ryegrass (as sown in Field 2), 40 lb. per acre; Certified pedigree white clover, 3 lb. per acre.

Herbage production in these three fields was measured by the Standard technique from 1942, and in early spring 1950 the other four cutting methods were also commenced in each field. Production was measured for two years by each of the five techniques described above. The trial area was under rotational grazing by sheep.

The frames for each technique were distributed at random in each of the fields, but no special provision was made to see that random placing was adopted each time the frames were shifted. The large number of frames involved made this impracticable. When shifted, each frame was moved to an unselected area usually within about 20 yd. of its previous position.

The areas cut for each technique varied somewhat, the hand-cutting methods (C and D) proving much more laborious than those methods using the mower. As time to cut is a factor that must be con-

	Area Cut	*Number of Frames*
Technique A	181.5 sq. ft.	3
„ B	121 „ „	2
„ C	50 „ „	2
„ D	50 „ „	2
„ E	121 „ „	2*

*Technique E required 4 frames per field but only 2 of these at a time were used to provide herbage for weighing.

sidered an integral part of each technique it was taken into account when deciding the area cut for each method. The area cut and numbers of frames for each technique in each field were as follows:

Dry-matter and Herbage-dissection Analyses

A composite sample of green herbage was secured at each cut from each technique in each field for the estimation of dry-matter percentage. Sampling errors are therefore based on green herbage weights from individual frames. At the same time, and in a similar manner, herbage samples were secured for dissection into species components. The relative proportion of species in such herbage was estimated on a dry-weight basis. Both dry-matter and herbage-dissection analyses were done at the Rukuhia Soil Research Station, Hamilton.

RESULTS OF THE EXPERIMENT

Estimation of Total Herbage Production

Table 1 compares the yearly production of dry matter of pasture herbage averaged over the three fields of the trial, as measured by the five techniques compared.

TABLE 1. DRY MATTER OF PASTURE HERBAGE: YIELDS IN LB. PER ACRE

Technique	1/9/50 to 31/8/51		1/9/51 to 26/8/52	
	Yield	Differences from "A"	Yield	Differences from "A"
A. Standard	11,380	—	10,240	—
B. Difference	10,240	− 1,140	6,670	− 3,570**
C. Difference Aust.	12,590	+ 1,210	9,270	— 970
D. Grazing Estimation	12,840	+ 1,460	10,420	+ 180
E. Rate of Growth	9,110	− 2,270*	7,820	− 2,420**
Sig. Diff. 5%*	1,820		1,200	
1%**	2,650		1,745	

The agreement between the two years is fairly good although both Difference methods have shown relatively poorer yields in 1951/52 than in 1950/51. In both years the yield by the Australian Difference method is significantly higher than by the New Zealand Difference technique. The former method does not use a prior trimming cut and, as explained earlier, the Difference technique of the Extension Division underestimates total production because trimming is made immediately grazing finishes. At times sheep graze closer than the mower can trim: such areas, therefore are not measured from a standard mowing height, and herbage production is underestimated.

The Rate of Growth technique (E), gives significantly lower figures than all techniques except the Difference method of the Extension Division. The effect is probably connected with the frequency of cutting. With Technique E, regular fortnightly cutting intervals are maintained in order to follow changes in production as closely as possible. All the

other techniques, because they are fitted in to a sequence of rotational grazing with sheep, are cut at approximately sheep-grazing height which means much less frequent cutting over most of the year. On the average 10 to 15 cuts a year would be made against 26 with the Rate of Growth technique. Another trial at the Marton Experimental Area shows how important is the effect of frequency of cutting on total herbage production.

This trial was established in spring 1949 on a sward of perennial ryegrass and white clover, and it compares (in replicated plots) cutting at weekly, 2-weekly, 3-weekly and 6-weekly intervals. After a 6-weekly cycle the trial is given a quick grazing before measurements of production are resumed. The effect of this over a 3-year period is clearly shown in Table 2.

TABLE 2. EFFECT OF FREQUENCY OF DEFOLIATION
(Period 28/9/49 to 14/5/52)

Cutting Interval	Dry Matter of Herbage lb./ac.	Yields relative to (1) = 100
1. Cutting at weekly intervals	8,680	100
2. „ „ 2-weekly „	12,040	139
3. „ „ 3-weekly „	14,650	169
4. „ „ 6-weekly „	19,710	227

The percentage difference between the 2-weekly and 3-weekly cutting intervals in the above trial (22%) is not greatly different from that between Techniques A and E in the technique trial (28%). On the average, Technique A would be cut at about a 3-weekly interval except during the winter period.

The Grazing Estimation method (D) gives figures which do not differ significantly from the Standard technique. As the amount of herbage removed with the Grazing Estimation method depends on the judgement of the technician, this result may reasonably be taken to show that the technicians in question operated the technique efficiently. It would have been interesting to see if other technicians would have produced a similar set of figures. Sears[3] states that this is "a good method so long as a very reliable team of workers is available, and also *constant* check is made within the field and with other measurements". The danger of obtaining a biassed result is very real with this method, and for this reason and for the reason of ease of operation, the authors prefer the impersonal removal of herbage with a mowing machine.

The Australian Difference technique (C) also gives yields not significantly different from the Standard method. It is, however, more laborious to operate but would have very real advantages on areas not suitable for the efficient working of a mower, such as on steep hillsides, on irregular ground, and in wet conditions. It does not use a prior trimming cut and it is interesting to see that the Standard technique, which measures growth from the uniform height left after trimming, does not give significantly different yields. If operated inefficiently, however, so that a heavy growth is removed when trimming, observations would

indicate a recovery growth of pasture not typical of that in the surrounding sward subject to grazing.

Effect of Technique on the Comparison of Production from Three Fields

Table 3 summarizes the production in each field as measured by the different techniques.

TABLE 3. DRY MATTER OF PASTURE HERBAGE: YIELDS IN LB. PER ACRE

Technique	Period 1/9/50 to 31/8/51			1/9/51 to 26/8/52		
	Field			Field		
	1	2	3	1	2	3
A. Standard	11,650	11,990	10,390	9,850	11,120	9,760
B. Difference	10,170	11,580	8,940	5,500	7,430	7,080
C. Difference Aust.	13,500	12,760	11,530	8,790	10,010	9,000
D. Grazing Estimation	14,610	11,960	12,120	10,380	11,360	9,560
E. Rate of Growth	8,640	8,800	9,510	7,170	7,680	8,610

This table shows that the different techniques do not all place the fields in the same order. Technique E gives the production of the fields in the order 3, 2, 1 in both years; with none of the other techniques is Field 3 first in either year, and in several cases it is last. Statistical analysis indicates that this is not a chance effect. As will be shown later, Technique E is as self-consistent as most of the other techniques. The reason for the discrepancy is that the techniques do not all measure the same thing. Technique E measures the production of grass cut fortnightly, and A measures the production of grass cut at a certain (approximate) height. When compared with A, E favours the short-rotation ryegrass of Field 3 at the expense of the perennial ryegrass of Field 1. (It will be remembered that Field 2 is a mixture of short-rotation and perennial ryegrass). This means that short-rotation ryegrass, which recovers quickly after cutting, produced more under regular fortnightly cutting, and perennial ryegrass produced more under cutting at sheep-grazing height.

Sampling Errors of Estimation of Production

Three frames of Technique A and two of each of the other techniques were cut in each field. This made it possible to calculate the error variance and standard error per frame of each technique. Two measures of the sampling error of the techniques are given in the tables: Table 4 compares the accuracy of the techniques for measuring the production of *one cut:* Table 5 compares their accuracy for measuring the production of *a season or a year*. Both sets of figures refer to the standard error of a single frame.

Table 4 shows for each technique the standard error per frame per cut as a percentage of the mean yield per frame per cut.

The seasonal and yearly totals for each frame and the standard errors of these totals for each technique were calculated. The standard error per frame per period total as a percentage of the yield for that period is given in Table 5.

In the figures in Table 5, the Grazing Estimation method (D) in most periods has the highest errors, but there is little difference among

TABLE 4. COEFFICIENT OF VARIATION PER FRAME PER CUT

Period	Year	A	B	C	D	E
		Standard	Diffce.	Aust.	Grazing Est.	Rate of Growth
Spring	1950	8.2	18.3	18.6	25.6	13.8
	1951	15.6	15.2	12.0	17.3	11.5
Summer	1950/51	23.8	15.3	27.3	33.1	15.3
	1951/52	15.8	32.8	28.8	21.8	16.4
Autumn	1951	21.4	8.7	20.5	16.0	19.7
	1952	23.7	11.4	21.9	20.7	18.8
Winter	1951	19.1	26.3	20.1	34.4	41.9
	1952	23.2	14.6	14.5	25.9	23.8
Year	1950/51	16.4	19.2	22.1	29.7	18.1
	1951/52	18.0	20.9	18.9	21.2	16.2

Each season is taken as a 3-monthly period based on spring as September, October, November.

TABLE 5. COEFFICIENT OF VARIATION PER FRAME PER PERIOD

Period	Year	A	B	C	D	E
		Standard	Diffce.	Aust.	Grazing Est.	Rate of Growth
Spring	1950	5.0*	5.0*	6.9*	15.2	5.8
	1951	10.3*	3.8*	7.3*	12.1	6.2
Summer	1950/51	18.5	8.0	17.7	21.4	7.9
	1951/52	4.6*	20.2	9.3	14.0	10.7
Autumn	1951	13.6	5.8**	9.6	12.3	17.0
	1952	12.0**	11.2*	21.8	20.9	10.2
Winter	1951	9.2**	23.0	18.7	14.7*	20.3
	1952	23.2	17.9	14.4	25.9	9.3**
Year	1950/51	2.9**	2.1**	8.5	13.8	4.3
	1951/52	6.6*	6.2*	5.7	7.1	5.4*

*Technique established significant differences between fields at 5% level.
**Technique established significant differences between fields at 1% level.

the other techniques, i.e. Technique D is less self-consistent than the others. The other four techniques may each measure something slightly different, but they measure it more accurately than does D.

Techniques A, B, and E each have an area cut of 60.5 sq. ft. per frame and Techniques C and D, 25 sq. ft. per frame. Since it is as much work to cut the smaller area of C and D as the larger area of the others, the single frame basis gives a fair comparison and the figures in the tables were *not* adjusted to equalize areas.

A frame of Technique A requires slightly less work than one of any of the other techniques, and so on a basis of equal work the A errors would be slightly lower in relation to those from other techniques than is indicated in Table 5.

When the seasons are considered invididually, the variation from one year to the next is rather large. In the winter period there are few cuts, and these are of low production. A chance abnormal production from a frame under any one of these techniques would, under such conditions, have a marked upsetting effect. In the spring period this is less likely to occur and here the high errors of the Grazing Estimation method (D) are outstanding when considering period totals. It was thought that the more frequent cutting, and therefore better sampling, with the Rate of Growth Technique (E) would give lower errors for this method in low production periods. This does not seem to be the case, possibly because the error of cutting and collecting herbage is relatively high (in relation to weight cut) when the amount of such herbage cut is small.

Differences in the Proportions of Pasture Species in the Herbage Removed by the Different Techniques

As described earlier, composite samples of the herbage removed by each technique were dissected into their species components and the proportions of each were estimated on a dry-weight basis. Table 6 shows the figures that were obtained for the main components of the sward, namely ryegrass (perennial and short-rotation), white clover (*Trifolium repens*), and other grasses, namely *Poa trivialis* and goosegrass (*Bromus mollis*).

It can be seen that for each field the Rate of Growth Technique (E) has shown less "other grasses" than the other techniques. This is reflected in an increase in the figures for ryegrass and white clover for Technique (E).

The explanation for this may be that these species probably recover more rapidly after cutting than do *Poa trivialis* and goosegrass. On the average, there is a shorter interval between cuttings on the Rate of Growth Technique, and consequently there would be a greater chance of securing more of the rapidly growing species.

The results show that the effect on herbage analyses of the interval between cutting (comparison Techniques A and E) has been greater than the effect of mowing (A) as compared with cutting to ground level (C) or plucking to imitate the grazing animal (D).

TABLE 6. MEAN PERCENTAGE OF PASTURE SPECIES IN THE CUT HERBAGE

The bracketed figures are based on incomplete information.

1. *Ryegrass* (perennial plus short-rotation)

Season	Field	A	B	C	D	E
Spring 1950	1	45	75	70	70	NA
	2	(30)	(60)	75	70	(75)
	3	50	75	80	70	NA
Summer 1950–1	1	Not available				
	2					
	3					
Autumn 1951	1	40	Not available			55
	2	45				60
	3	60				65
Winter 1951	1	40	35	30	30	(45)
	2	65	55	50	80	(50)
	3	60	75	70	75	(80)
Spring 1951	1	40	40	40	45	50
	2	50	55	45	45	65
	3	60	65	65	60	75
Summer 1951–2	1	30	20	30	35	40
	2	30	40	30	45	55
	3	30	50	50	50	65
Autumn 1952	1	70	60	60	70	65
	2	65	60	60	55	65
	3	55	60	70	85	60
Winter 1952	1	Not available				
	2					
	3					

2. *White Clover:*

Spring 1950	1	10	10	5	5	NA
	2	(5)	(10)	5	5	(10)
	3	10	5	5	5	NA
Summer 1950–1	1	Not available				
	2					
	3					
Autumn 1951	1	5	Not available			20
	2	20				20
	3	10				20
Winter 1951	1	—	5	—	15	(5)
	2	5	—	10	5	(5)
	3	5	5	5	—	(5)
Spring 1951	1	5	5	5	5	10
	2	10	5	15	10	10
	3	10	10	5	5	5
Summer 1951–2	1	15	15	20	20	20
	2	15	10	15	10	20
	3	10	20	15	15	20
Autumn 1952	1	5	15	5	5	10
	2	5	10	10	10	5
	3	15	15	10	10	10
Winter 1952	1	Not available				
	2					
	3					

3. *Other Grasses:*

Season	Field	A	B	C	D	E
Spring 1950	1	45	15	25	25	NA
	2	(65)	(30)	20	25	(15)
	3	40	15	10	25	NA
Summer 1950–1	1					
	2			Not available		
	3					
Autumn 1951	1	50				25
	2	30		Not available		15
	3	25				10
Winter 1951	1	60	60	70	55	(50)
	2	30	45	40	15	(45)
	3	30	20	25	25	(15)
Spring 1951	1	55	55	55	50	40
	2	40	40	40	45	25
	3	30	25	30	35	20
Summer 1951–2	1	55	55	50	40	30
	2	55	50	55	45	20
	3	55	20	30	30	5
Autumn 1952	1	25	15	25	20	25
	2	30	30	30	35	30
	3	20	15	20	5	25
Winter 1952	1					
	2			Not available		
	3					

Discussion and Conclusions

The results from this comparison of some of the various techniques used when operating frames to measure pasture production have shown that figures secured from frame technique experiments must be considered in relation to the cutting method employed.

Considerable controversy exists with regard to the effect of pre-trimming cuts on the measurement of pasture production. Linehan, Lowe, and Stewart[5] object to methods using pre-trimming. They say "The general effect . . . on yield estimates would probably be: (a) if the sward is not fully grazed to the level of the pre-trimmed area, the yield estimate will be too high; (b) if the grazing period is short and stocking heavy, yield estimates will be too low; (c) if the grazing period is prolonged sufficiently, the growth of herbage on the pre-trimmed site, although at first slower than outfield, will in time exceed that outfield, since the latter is being continuously impeded through defoliation by grazing animals and the net effect would be to exaggerate yields".

These workers were concerned with bullocks grazing in periods of 1 to 2 weeks. The trial discussed in this paper was under rotational grazing with sheep, where the grazing period was short and the stocking heavy, but where at most times of the year the sward would not be "fully grazed to the level of the pre-trimmed area". According to Linehan *et al.*,[5] these two conditions work in opposite directions. It is interesting to note that Methods A, B, and E, which use pre-trimming,

have in the present trial, differed at least as much among themselves as the comparison between any one of them and Technique C and D which do not measure production from a pre-trimmed area. In the opinion of the writers, the effects of the length of the interval between cutting and of the efficiency of the measurement technique far outweigh the effect of the pre-trimming cut.

Pre-trimming has many practical advantages, especially with techniques using the mower. It gives a measurement free from the sampling variation which exists when adjacent areas are cut to estimate herbage present on the measurement area prior to the mowing period. It gives clean herbage samples for botanical and chemical analysis. If pre-trimming is made when all herbage is above "mowing height", production is estimated directly from the height after mowing as a uniform basis for measurement. Admittedly care must be taken not to remove too heavy a volume of material in the pre-trimming cut, and so open-up the sward unduly, but this is easily secured with reasonable care in sward management. Pre-trimming can be made to any desired height, providing the measurement cut is also made to the same height. Close defoliation is not necessary, and indeed, may be undesirable, particularly where pasture-production measurements are being made under cattle grazing.

Williams[6] and Cowlishaw[7], working in England, produce evidence that certain types of frame enclosures, particularly those completely closed-in with wire-netting, exert a protective effect which is reflected in a more favourable microclimate for growth and in better growth than outfield. Interim results from some trials now in progress in New Zealand support their findings, although it is probable that the high-sided open-at-the-top type of frame as used in the technique trials described in this paper gives less protection than the low covered-in frame. In the present series, this effect would be uniform for all techniques, except that the open cut as operated in the Australian Difference Technique (D) is made outside the frame. The size of the error introduced by this factor would seem to be less than the effects of the cutting technique that have been discussed. For comparisons among treatments the protective effect of the frame should operate equally on all treatments, although estimates of total pasture production are perhaps exaggerated in some degree by the use of frames. Trials are now in progress at three widely-separated centres to measure these effects with different types of frames so that, if possible, a correction can be made to total-production measurements.

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A VACUUM PLANT FOR REMOVING EXCESS WATER FROM HONEY

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Summary

In certain areas of New Zealand, honey is often found to contain excess water. An efficient plant for removing this water is described.

The honey is exposed in the plant to a vacuum as it flows down the inside of a cylinder heated externally with steam. Water removed from the honey by the vacuum is condensed and collected in a vacuum tank.

Darkening of honey passed through the plant was negligible and flavour was generally improved.

The plant is capable of removing 2% of water in eight hours from 2.5 tons of honey.

Introduction

Usually the sugar concentration of honey is sufficiently high to prevent yeast growth. However, if the water content of the honey rises above a certain point the sugar concentration is so reduced that yeast growth and fermentation are liable to occur. In practice it has been found that for safe keeping over long periods honey should contain no more than 17.2% water.

Honey exported from New Zealand is usually marketed in Britain, so that a long period elapses between extraction and consumption. Hence all honey exported must be examined by the Honey Grader who rejects lines containing more than 17.2% moisture.

Although the beekeeper may take every precaution during extraction and processing to prevent the entry of moisture into the honey, he is powerless to alter its condition prior to extraction.

In New Zealand it has been shown by Fix and Palmer-Jones[1] that the main cause of fermentation in extracted honey is excessive water in honey combs removed from the hives fully capped and apparently ripe for extraction.

There is no doubt that in certain areas of New Zealand, where the relative humidity is frequently high, the bees find it very difficult to evaporate off as much moisture as usual from the honey during ripening, and such honey, when extracted, is often found to contain more than 17.2% of water. In seasons of unusually high humidity, the water content of all the honey extracted in some districts exceeds the standard. The quantity of honey with excess water produced in a year has been estimated at some 200 tons.

Some years ago Fix and Palmer-Jones[1, 2] designed a drying plant for the removal of excess water from honey. The plant depended on the circulation of warm, dry air, in comb and tank drying rooms, and appeared to give satisfactory results. However, a succession of wet seasons resulted in much more honey than usual being produced with a high water-content, and it was found that this method could not cope

Fig. 1.—General view of vacuum plant.

with the problem. In an endeavour to increase the efficiency of the drying rooms, refrigeration was used to remove moisture from the circulating air by passing the warm, moist air over a cooling coil coupled to a refrigeration unit. This reduced the relative humidity to 8%, but the cost of such an installation is over £200, and even with its help drying would not always proceed fast enough for the convenience of beekeepers.

While the above work was being carried out, Messrs. L. G. Baker and A. W. Hanson, beekeepers of Orini, were also experimenting with the use of hot air for drying honey, but finally abandoned the method and concentrated on developing a vacuum process. In a very short time they had in operation a plant which very definitely reduced the water content of honey passed through it. The authors were privileged to view the plant in operation and consider that they were saved much preliminary work by the co-operation of Messrs. Baker and Hanson.

EXPERIMENTAL PROCEDURE

Laboratory Experiments

Laboratory experiments were carried out to determine the temperature at which honey boiled when both the vacuum to which it was exposed and its water content were varied.

Two litres of clover honey was placed in a flask held in a water bath. An accurate vacuum gauge was connected to the vacuum lead from the flask in which a thermometer was immersed in the honey. The temperature of the water in the water bath was raised until the honey boiled. The honey was considered to boil when frothing and bubbling took place and water vapour came off vigorously. Although the water content of the honey was raised one per cent at a time, from 16.0% to 21.0%, and the b.p. obtained for three vacuums at each stage, only the end results are given in Table 1, because the effect upon the b.p. of varying the water content over this range was small.

TABLE 1. EFFECT OF VACUUM ON THE BOILING POINT OF HONEY

% Water in Honey	Vacuum (In. Hg)		
	25.5	26.5	27.5
	B.P.°F.		
16	160	151	134
21	154	143	130.5
Water alone	130	120	107

Note: Throughout this paper the water in honey is expressed as a percentage by weight.

Experimental Plant

An experimental plant for the vacuum drying of honey was designed and set up. A description of this plant is not given here as it is essentially the same as the improved version described later.

When the plant was operating at a vacuum of 27.5 in., fifteen runs of various honeys, all entering it at 90°F., left at an average temperature of 136.5°F. The effect of the treatment on colour and flavour was slight according to Mr. R. S. Walsh, Honey Grader for the Department of Agriculture.

The plant was estimated to be capable of removing approximately 2% of water per minute per quarter gallon of honey entering it at 90°F. which is equivalent to treating approximately 1,700 lb. in 8 hours.

These results were so encouraging that the larger and more efficient plant now described was constructed.

Plant

The plant consists essentially of a steam-jacketed vacuum cylinder, connected through a condenser to a vacuum tank and pump. The honey is pumped into the top of the vacuum cylinder, and, during its flow down the inside wall, excess water is removed. Finally it is delivered through a releaser unit which is operated by a pulsator.

In designing the plant, milking machine parts were used as much as possible. When choosing equipment, consideration had to be given to the strength of material, because milking machine units run under a normal vacuum of 15 in. whereas this plant ran at almost a maximum vacuum.

Consult Figs. 1 to 4 throughout the description.

Vacuum Cylinder. The vacuum cylinder consisted of an inner tube of 18-gauge stainless steel 4 ft. 6in. long, slightly tapered. The top diameter was 11 in. and the bottom diameter 9 in. The taper was considered necessary to keep the honey in close contact with the heated walls of the cylinder. Both ends of the cylinder have substantial flanges, the cylinder cap being secured to the top one and the releaser to the bottom one.*

A copper cylinder of approximately 12½ in. diameter, which acts as the heating compartment, is attached to the stainless steel cylinder. Steam is admitted at the top and the condensate runs out at the lower opening.

A dial thermometer is placed near the bottom of the steam jacket, immediately above the condensate discharge, to measure the temperature, which should be maintained at 212°F. The temperature is regulated by adjusting a valve controlling the steam supply.†

The domed cap or top of the vacuum cylinder, which must be detachable, is made of stainless steel, with a flange corresponding to that on the cylinder top. About 1 in. protrudes through the flange to hold the rubber sealing ring in place and to act as a register in placing it in position on the vacuum cylinder. In the centre of the cap is the vacuum pipe, a 1¼ in. water pipe which passes right through the honey distributing plate, a circular disc with a diameter approximately 1/32 in. less than that of the vacuum cylinder at the point of suspension; the plate screws on to the vacuum pipe. It was found that distribution of the honey by this means was not altogether satisfactory. A method of

*Wire rings spaced on the inside of the vacuum cylinder had the effect of reducing the rate of flow of the honey and increasing the area of its surface exposed to the vacuum. However, their use is not recommended because honey lodges on them, becomes overdried, and leaves the plant in a lumpy condition.

†Originally an electric element and thermostat were used to provide hot water as a heating medium. However, this failed to maintain the water at boiling point when large quantities of honey were treated. Steam was then used without water in the cyclinder and resulted in the maintenance of a constant temperature over a 45-min. run. The use of steam permits the outer jacket to be constructed as a plain cylinder without compartments for electric element, etc.

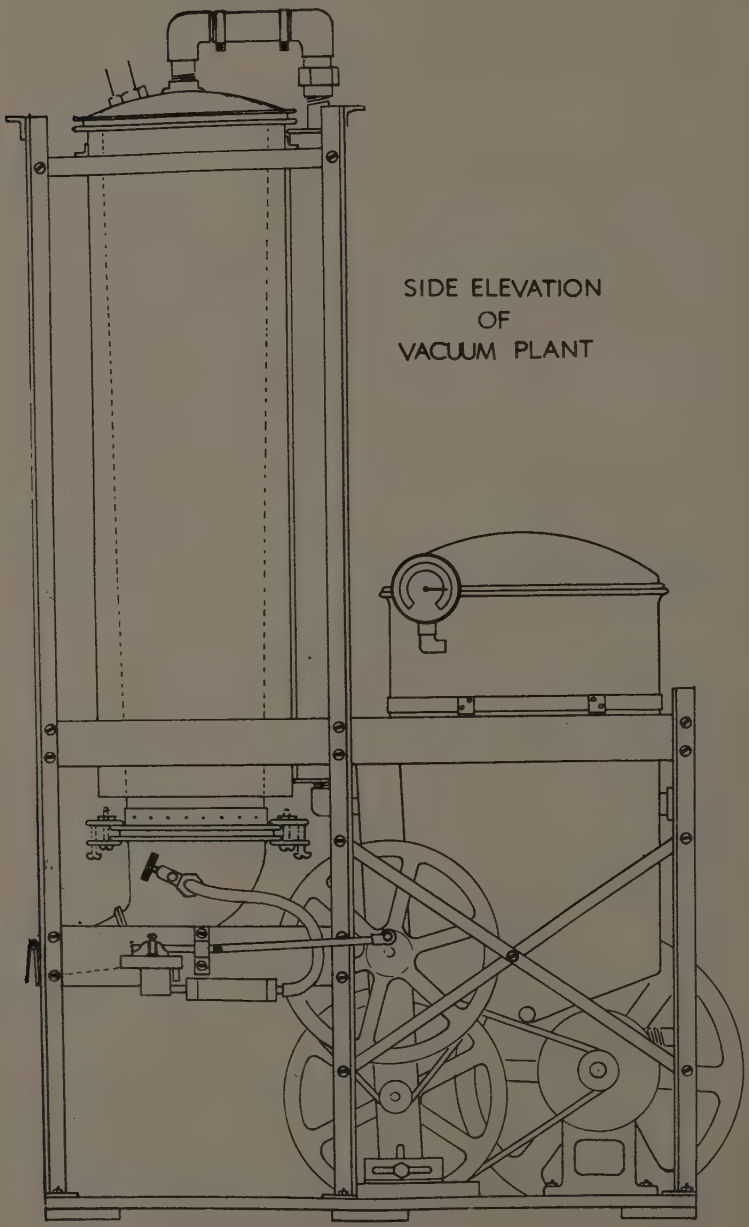

Fig. 2. Side elevation of vacuum plant.

spreading the honey evenly round the entire surface of the vacuum cylinder was required. A satisfactory spread was obtained by soldering a cylindrical piece of sheet metal about 2 in. deep on the top side of the distributing plate, and boring a series of small holes around the circumference just where it met the plate. The holes are of such a size that they cause the honey to build up inside to about 1½ in., so giving sufficient head to shoot the honey evenly out of the holes on to the sides of the cylinder.

The depth of the ring and the size of the holes was determined by pumping honey in and increasing the size of the holes until the head of honey remained constant at about the 1 to 1½ in. level.

The honey inlet to the cap is off centre and placed so that the honey will drop into the distributing compartment.

It is considered desirable to have the cap and vacuum lead to the condenser covered with insulating material to prevent premature condensation of water vapour which might result in water being trapped inside the cap.

Condenser. The outer casing of the condenser, 3 ft. 8 in. long with a diameter of 4 in., was constructed of copper. Inside were three 3 ft. 4 in. by ¾ in. copper tubes brazed into end plates. Brass plates at top and bottom provided suitable material into which to screw pipes for the vacuum lead. Tubing was brazed into the outer casing to take rubber hose for the water circuit.

Overheating of the vacuum pump will occur if water vapour drawn from the vacuum cylinder is not completely condensed. The rate at which cooling water enters the condenser should, if possible, be regulated so that it leaves at a temperature not exceeding 70°F.

Vacuum Tank. The tank used was 25 in. long with a diameter of 18 in. The domed top was removable, but this is unnecessary, and the possibility of air leaks would be eliminated if the whole unit were sealed. A control valve is set at the lowest part of the tank to drain off the condensed water. A water gauge can be incorporated in the unit to indicate the volume of water. The maximum water level should be well below the lead into the vacuum pump. Allowance for approximately 5 gal. of water would be ample for, say, a four-hour run.

A standard vacuum gauge is screwed into the vacuum tank.

Vacuum Pump. Use was made of readily available milking-machine vacuum pumps. The smallest size, which had a capacity of approximately 7 cu. ft. per minute (15 in. vacuum), was found after many trials to have insufficient capacity, and a standard Masport pump which ran at a much slower speed and had a capacity of approximately 13 cu. ft. per minute at 188 rev./min. (15 in. vacuum) was installed. The efficiency of these pumps depends on a regular supply of lubricating oil. Uusually they are run for approximately 1½ to 2 hours at a time and the oilers supplied generally hold sufficient oil for such a run. For use in a honey-drying plant larger oilers are required, giving sufficient oil for at least a four-hour run. The vacuum pump has a shaft extending on both sides, which allows for the driving motor on one side and the drive for the pulsator on the other. The speed of the pump,

188 rev./min., was attained by having a 3 in. driving pulley on the 1 h.p. electric motor and a driven pulley of 20 in. on the pump. The maximum recommended speed of these pumps is 300 rev./min. This pump gives satisfactory results at the lower speed, and, since it is not running to capacity, it has power in reserve if required.

Releaser Unit. Removal of honey from the vacuum cylinder is effected by means of a standard milking-machine releaser unit, the upper portion A having a flange for a cylinder of 9 in. diameter sealed by a rubber ring to the bottom of the vacuum cylinder (Fig. 3). A narrow rubber ring fits in a groove on the lower end of A where a metal flap, pivoted to open outwards, is attached. The spit chamber B has a similar arrangement. These flaps should be made of light metal and suspended so that they hang loosely against the rubber rings. A tube near the top of the spit chamber leads to a vacuum source through the pulsator. The spit chamber is securely fixed to the releaser by means of a rubber ring and flange nuts. The releaser cannot operate unless

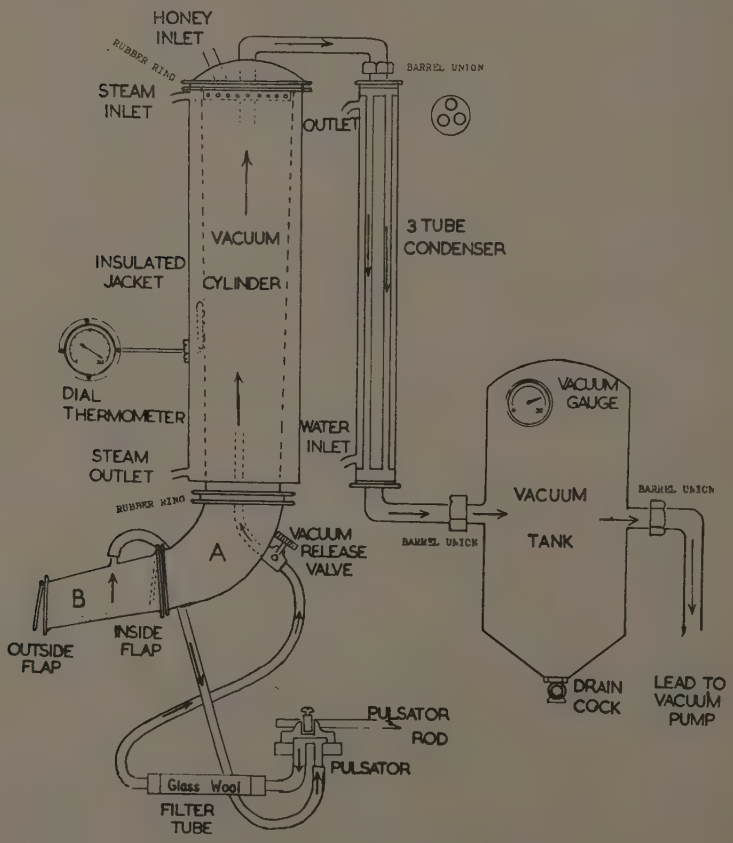

Fig. 3.—Diagrammatic view of vacuum plant.

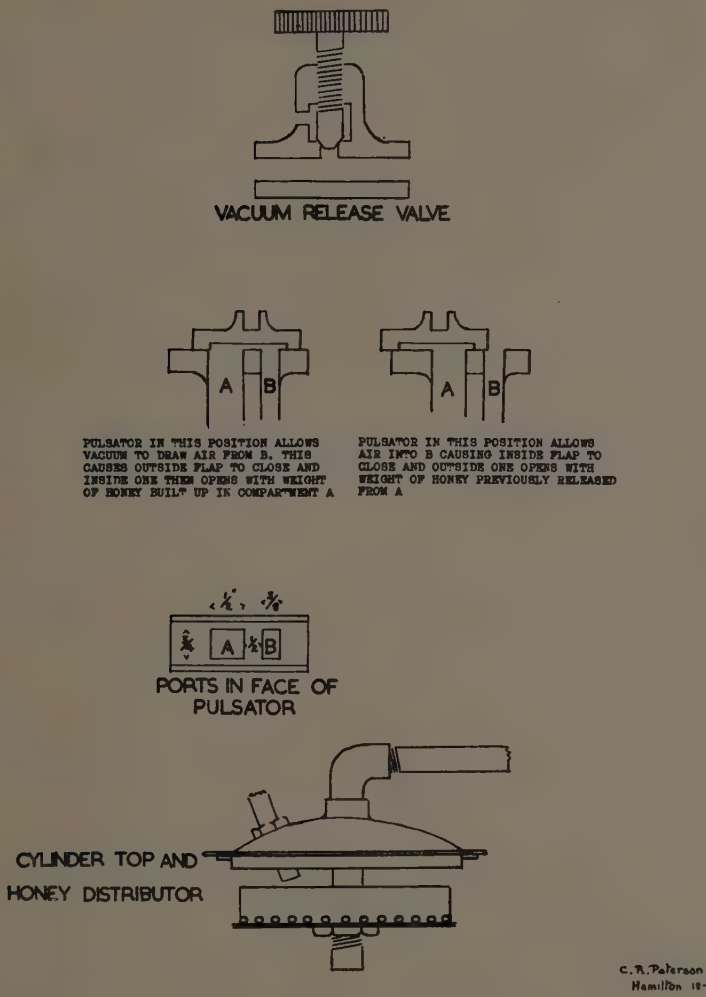
VACUUM RELEASE VALVE
A
B
PULSATOR IN THIS POSITION ALLOWS VACUUM TO DRAW AIR FROM B. THIS CAUSES OUTSIDE FLAP TO CLOSE AND INSIDE ONE THEN OPENS WITH WEIGHT OF HONEY BUILT UP IN COMPARTMENT A
A
B
PULSATOR IN THIS POSITION ALLOWS AIR INTO B CAUSING INSIDE FLAP TO CLOSE AND OUTSIDE ONE OPENS WITH WEIGHT OF HONEY PREVIOUSLY RELEASED FROM A
A
B
PORTS IN FACE OF PULSATOR
CYLINDER TOP AND HONEY DISTRIBUTOR
C. R. Paterson
Hamilton 18-5-54

Fig. 4.—Details of vacuum plant.

an intermittent vacuum is created in the spit chamber, and a milking-machine pulsator is used for the purpose.

Pulsator. The pulsator is essentially a sliding valve which subjects the spit chamber to vacuum and normal air pressure alternately. For honey, the rate of pulsation should be 5 to 7 per minute.

The pulsator is constructed in such a way that the main port A is connected to the vacuum line and the smaller port B leads to the releaser (Fig. 4). When the slide valve covers both ports air is exhausted

from the spit chamber, so allowing the honey in the vacuum cylinder to come past the first flap but not past the second one because the compartment closed by this is under vacuum. The valve in the pulsator then moves so that the small port is uncovered, thus admitting air to the spit chamber where it immediately causes the top flap to close. The weight of honey in the spit chamber is capable of opening the lower flap, thus finally releasing the honey from the vacuum system. The pulsator must be adjusted so as to allow only a certain amount of honey to be drawn into the spit chamber each time; if too much enters, it will be sucked up into the pulsator. The vacuum lead to the pulsator is taken from a fitting at the lower end of the vacuum unit. The reason for making the connection here is to allow the air, which is taken from the spit chamber at each pulsation, to flow up the centre of the vacuum cylinder; it will mix with the water vapour coming off the honey and leave the top to enter the condenser. A release valve, fitted into the lead from pulsator to vacuum unit, is used for breaking the vacuum prior to shutting off the vacuum pump.

Power Drive for Pulsator. In milking-machines the pulsation rate is 30 to 40 per minute. As honey is very much more viscous than milk, greater time has to be given for the honey to move from one compartment to another. A rate of 5 to 7 per minute appears to give satisfactory results. A train of pulleys had to be used to obtain this speed when taking the drive from the shaft of the vacuum pump. These were built up in a unit so that belts could be easily adjusted. The pulleys were mounted on a steel arm, pivoted at the top and free to move along a slot for a couple of inches, thus allowing the belt from the pump to be adjusted. The two large pulleys have their short shafts running in a long brass bearing. The bottom one is fitted in slots which permit adjustment of the belt between the large and small pulleys.

The various pulley sizes are as follows:

Pulley on pump shaft	3 in.
„ to countershaft	15 in.
„ on countershaft	2 in.
„ to pulsator drive	15 in.

The crank driving the pulsator rod is offset $\frac{3}{4}$ in., thus giving a stroke of $1\frac{1}{2}$ in.

The slide of the pulsator is kept running freely by applying oil sparingly at frequent intervals. This oil can be prevented from entering the vacuum line by fitting a trap between the pulsator and the vacuum cylinder. A glass tube filled with glass wool provides a visual method of control.

Supply of Honey to Cylinder. During the first experiments the flow of honey into the vacuum cylinder was controlled by a valve in the pipeline. Considerable difficulty was experienced in adjusting the rate of flow correctly by this means. Sucking the honey up from floor level by vacuum did not prove very satisfactory and was inclined to overload the pump. A separate pumping unit was then used which gave completely satisfactory results. Honey at a temperature of 90–100°F. was run through the pump and the rate of flow noted; pulleys were changed until the required rate of nine 60-lb. tins (540 lb.) per hour

was obtained. The speed of the pump was 44 rev./min., and the pulleys used were:

On motor	2 in.
to countershaft	14 in.
countershaft	2 in.
to pump	10 in.

Method of Operation. Before commencing a run, all vacuum joints are checked for tightness. The flaps in the releaser are inspected to see that they are perfectly free. The water supply to the condenser is turned on. The steam valve is slowly opened as the cylinder warms up, and steam is increased until the temperature gauge registers 212°F. The vacuum pump is now started, and, as soon as the gauge reaches 27 to 27.5 in., the honey pump is switched on. As honey commences to flow down the inside of the vacuum cylinder more steam will be needed to maintain the required temperature. In a short time honey should commence to leave the releaser. The plant will then run without any further attention other than normal routine checks.

The treated honey can be run into suitable tanks either by gravitation or by an automatically controlled honey pump.

In stopping, a definite procedure should be followed:

1. Switch off honey pump.
2. Open release valve to break vacuum.
3. As soon as vacuum gauge has returned to zero switch off vacuum pump.
4. Unless the plant will be used again immediately, take off spit chamber of releaser and clean flaps in warm water. If honey is allowed to cool here it will set quite hard and be very difficult to remove. Hence the vacuum should be broken as soon as the honey has stopped flowing from the pump.
5. The condensate in the vacuum tank should be drained off, and the quantity noted, as its volume will give a rough indication of how efficiently the plant has run.

Running Costs. The main cost in running the plant would be that of steam supplied. Measurement of the condensate from the heating jacket over the period of a trial run indicated that approximately 60 lb. of steam per hour would be required. A small boiler capable of converting into steam 60 to 70 lb. of water per hour would meet the heat requirements of the plant. The steam pressure necessary would be 2 to 5 lb. per sq. in.

Cost of Plant

Standard vacuum pump	21	2	6
1 h.p. electric motor	23	10	0
Vacuum tank (second hand)	7	10	0
Releaser (second hand)	3	0	0
Pulsator (second hand)	1	5	0
Vacuum gauge (second hand)		15	0
Iron work for frame, etc.	4	12	6
Wooden base	1	0	2
Material for condenser	5	0	0
Vacuum cylinder. Stainless steel with cap and copper outer jacket	62	15	2
Pulleys and belts, etc.	9	15	0
Pipe fittings	3	10	0
Sundries	6	4	8
TOTAL	£150	0	0

The cost of pumping units and steam boiler would be extra. The above estimate is for material only and does not include the cost of assembly.

RESULTS OF TRIAL RUNS

Various honeys were run through the plant, results being summarized in Table 2(a). Small volumes of honey were put through the plant, as the main object of these tests was to discover what effect the treatment would have upon the colour and flavour of the honeys. The drying action for each run is expressed, for purposes of comparison, as gallons of honey which would be reduced 2% in water content per hour.

The honey was fed into the plant by gravity, except for run No. 8, when a honey pump was used. The pump would prevent any overloading of the plant above the spreader and so account for the greater drying of the honey which occurred in this run.

The maximum temperature at which the honey left the plant was 142°F. (No. 8).

Honey was sampled before and after treatment and the samples submitted to Mr. R. S. Walsh, Honey Grader, Department of Agriculture, for examination.

Mr. Walsh's report is summarized in Table 3.

Here it is seen that in all lines except two the flavour was improved and the loss of colour was negligible. The two lines that did not improve in flavour were apparently overheated by the producer before they were put through the plant.

Mr. Walsh considers that the all-round improvement in the treated samples is due to the vacuum method restoring the honeys to their natural condition. In other words, the removal of excess moisture restored the natural flavour of honeys which had lost flavour points because of insipidness brought about by dilution. The loss of one to three colour points is attributed to the fact that the honeys had become more concentrated.

TABLE 2. RESULTS OBTAINED WHEN HONEYS RUN THROUGH PLANT

Type of Honey	(a) Short Runs													(b) Long Runs	
	Clover	Mixed	Clover & Bush	Butter-cup	Clover	Clover	Rewa-rewa	Manuka	Clover	Mixed	Kamahi	Mixed	Clover	Clover and Mixed Sources	Mixed Honeys Predom-inantly Dark
Temp. honey entering plant °F.	80°	85°	98°	104°	105°	119°	119°	119°	122°	125°	127°	132°	142°	100°	95°
Temp. honey leaving plant °F.	125°	124°	123°	133°	126°	139°	132°	142°	129°	136°	138°	130°	139°	135°	142°
Vacuum (in. Hg)	27.5–28	27	27.5	27	27.5	27.5	27	27	27	26–27	27.25	27	27	27	26.5
% Water start	18.3	18.8	19.3	19.9	18.2	18.2	19.4	18.9	18.2	19.5	19.0	19.2	17.4	17.7	18.5
% Water end	16.3	17.5	18.2	16.0	16.8	15.2	15.9	15.2	16.5	17.2	16.3	17.1	14.2	14.8	15.4
% Water lost	2.0	1.3	1.1	3.9	1.4	3.0	3.5	3.7	1.7	2.3	2.7	2.1	3.2	2.9	3.1
Volume run (gal.)	3.5	2.75	3.75	4.0	3.5	4.0	3.0	4.0	4.0	2.75	4.0	2.75	4.0	27.0	23.0
Time of run (min.)	12.0	4.1	5.0	13.0	5.0	10.0	7.0	7.0	9.0	4.1	5.7	4.1	7.0	45.0	42.0
Gallons run per minute, approx.	0.3	0.7	0.75	0.325	0.7	0.4	0.43	0.6	0.44	0.67	0.7	0.7	0.6	0.6	0.55
Gallons per hour reduced 2% water	**18**	**27**	**25**	**38**	**29**	**36**	**45**	**66**	**22**	**46**	**57**	**44**	**57**	**52**	**51**
Run No.	1	2	3	4	5	6	7	8	9	10	11	12	13	1	2

Note: 1 gallon of honey with sp. gr. 1.420 weighs 14.2 lb.

TABLE 3. EFFECT OF TREATMENT ON GRADING OF HONEYS

Run No.	Type Honey	Flavour (Max. 100 points)		Colour (Max. 100 points)		Remarks
		Before Treatment	After Treatment	Before Treatment	After Treatment	
1	Clover	95	96	85	83	Condition excellent. Flavour improved.
6	Clover	90	92	63	61	Condition excellent. Flavour improved.
9	Clover	80	80	17	14	Condition impaired by prior overheating by beekeeper and neither flavour nor condition could be improved.
7	Rewarewa	85	85	34	31	Condition excellent. Flavour improved but not sufficiently to increase points.
4	Buttercup	80	80	15	14	Remarks as for No. 9.
8	Manuka	80	85	29	27	Improvement in flavour and condition is surprising.
11	Kamahi	80	80	60	58	Condition excellent. Flavour improved slightly. A "difficult" honey at all times.
3	Clover & Bush	85	85	37	36	Condition excellent. Flavour improved but not enough to gain points.

Table 2(b) shows results obtained when honey was pumped through the plant for periods of up to three-quarters of an hour at temperatures which would be convenient to use in practice.

The plant functioned efficiently throughout, and water was removed from the honey at a rate in very close agreement for both runs. Several runs of from 2 to 3 hours gave similar results.

These tests proved the plant capable of removing 2% of water in eight hours from 2.5 tons of honey.

Discussion

In removing excess water from large volumes of honey it would not always be necessary to pass all the honey through the plant. The plant, as adjusted at present, removes approximately 3% of water from honey. In the case of honey containing less than 3% of excess water it would suffice to pass a sufficient volume through the plant to reduce the water content of the remaining untreated honey to the correct level when both honeys were thoroughly mixed.

Extracted honey seldom contains more than 21% of water, and usually drying in a plant would not be allowed to proceed below 17.2%. Table 1 shows that over such a range the rise in boiling point attendant on concentrating honey, which is essentially a sugar solution, is small.

The greater the water content of honey entering the plant the faster will water be removed. If the water content exceeds 20% the condenser cannot deal with the volume of water leaving the honey and the vacuum pump will overheat and lose efficiency. Such honey should be run through the plant at a much slower speed than usual, or the cooling surface of the condenser increased.

If the plant is operated as usual when the water content of honey entering it is only slightly above 17.2% the honey will be dried out too much and its high viscosity will prevent the releaser flaps functioning properly. Excessive drying of such honeys can be avoided by running the plant at a lower vacuum than usual, say 25 in. The lower vacuum is obtained by adjusting the release valve.

The closer the temperature of the honey entering the plant is to the temperature at which boiling occurs, under the particular vacuum being applied, the more efficiently will water be removed from the honey. In practice it would usually be most convenient to run honey into the plant at 90–100°F. The highest vacuum obtainable in the plant, with a vacuum pump of the type available commercially, was 27.5 in.

The pulsation rate of 5 to 7 per minute recommended is directly related to the rate of flow of honey through the plant. If the flow is increased, the pulsation rate also must be correspondingly increased or the spit chamber will flood and honey will be drawn through the pulsator.

Frequent checks must be made on the water content of honeys when operating the plant. The Chataway hydrometer, which is generally used for such estimations, is incapable of giving results quickly. Also, air bubbles must be removed from honey before it is floated, and it is completely inaccurate when used in certain types of bush honey. For these reasons a refractometer[5] was used in its place. This instrument gives results quickly, is unaffected by bubbles, and can be used for all types of honey though, in the case of bush honeys, allowance should be made for a variation of plus or minus 0.5% (Pers. comm. Mr. K. M. Griffin, Government Analyst, Dominion Laboratory, Auckland). The laboratory model employed is an expensive and somewhat delicate instrument. However, a refractometer has been specially developed for such estimations by the Bausch and Lomb Optical Co. of New York. It is robust, easy to operate, and relatively cheap.

The Fiehe test[3] is sometimes used to determine if honey has been adulterated with commercial invert sugar. The test is an unsatisfactory one for various reasons. Thus it may give a positive reaction with pure honey that has been overheated[4]. Honey passed through the drying plant is not overheated in any way and a positive Fiehe reaction would not be expected. However, the test was applied to eight samples of various honeys before and after treatment. A negative reaction was obtained in all cases.

It has been shown that the flavour of honeys passed through the plant is usually improved and darkening of colour is negligible. The

physical properties of treated honeys appear unaltered and they granulate well after the addition of a starter.

The capacity of the plant is such that it could handle all the honey with a high water-content produced in a season. It would be most economic to establish it in the depot used for the marketing and export of honey. Here honey requiring treatment could be dealt with for a charge sufficient to cover operating costs.

The capacity of the plant could easily be increased by lengthening the vacuum cylinder and using a more powerful vacuum pump. However, it is considered that its present size is the optimum for current New Zealand conditions.

Acknowledgements

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A SURVEY OF FACTORS AFFECTING WHEAT YIELDS IN SOME PARTS OF CANTERBURY

By Jean G. Miller, Extension Division, Department of Agriculture, Wellington

(Received for publication, 23 August 1954)

Summary

From a sample survey in an area near Christchurch for 1945 to 1950 it was shown that in wheat crops the standard fertilizer was 1 cwt. per acre of superphosphate, Cross 7 was the variety grown in 67% of the fields, certified seed was used in one third of the crops, and there were many different rotations. Significantly better yields were obtained from wheat after grass, or from wheat as the second crop after grass, than from wheat after two or more other crops.

In a similar survey in Ashburton County from 1947 to 1952, soil type was shown to be the factor exerting the greatest influence on yield, with smaller differences between spring and autumn sowing, and between rotation histories. Best yields were obtained after peas irrespective of whether that crop followed pasture or another crop.

Details of the assumptions made and methods of calculating the estimates of the yield effects are given.

Introduction

Few studies have been made in this country on the relationships between wheat yields and crop management practices, on a farm scale, or on the patterns of practices which are being used by farmers. In the course of an investigation into the economics of wheat growing in 1933, Krause conducted a survey on 200 selected wheat growers, and the results of this survey are quoted by Hilgendorf (1939).

Scope of Survey

For a period of five years, information was collected from co-operating farmers in two Canterbury districts—one near Christchurch and one near Ashburton—on their methods of wheat-growing and the associated yields. The purpose of the survey was to determine which factors had the greatest effect on yield, and whether deviations from standard practices produced marked increases or decreases in yield.

In the first years, information was obtained on many factors: date of sowing, variety used, rate of seeding and of fertilizer application, soil type, previous cropping history, cultivation history since the previous crop, grade of seed and origin, treatment of seed, and the harvested yield. Later it became apparent that the effects of some of these factors were either very small or indeterminate, so they were omitted from the survey.

The survey was begun in the Christchurch district in 1945 on an area that was selected because of its apparent homogeneity of soil type and of farming pattern. However, a detailed soil survey later showed that there were marked differences within the area. In 1947, work was begun in the Ashburton district on an area which covered some light and some heavy land. Two regions included in the survey are shown in the accompanying maps and may be described as:—

Christchurch area—parts of the districts of Yaldhurst, Prebbleton, Templeton, Springston, Broadfields, and Weedons.

Ashburton area—parts of the districts of Methven, Lyndhurst, Winchmore, and Rakaia.

Methods of Carrying out the Survey

When the areas had been defined, farmers were asked to co-operate and a panel was formed in each area of those willing to supply the desired information. During the years, these panels were slightly reduced as a few farmers withdrew or ceased to grow wheat, and no replacements were brought in. Details were recorded separately for each wheat-growing field each year. The fraction of the wheat acreage of the districts covered by the survey each year was not known, and no attempt was made to have the panel chosen so as to give a statistically valid sample of the area. This is not likely to cause serious error in the assessment of the "cause and effect" relationships but it must be considered when reading any tables showing the relative frequency of different practices.

TABLE 1. NUMBER OF FARMS AND TOTAL ACREAGES

Christchurch				Ashburton			
Year	No. Farms	No. Fields	Area	Year	No. Farms	No. Fields	Area
1945/46	42	81	1262	1947	91	154	4430
1946	33	64	1061	1948	72	131	3936
1947	32	70	1033	1949	64	111	2920
1948	34	71	1258	1950	62	113	2932
1949	33	72	1182	1951	51	86	2069

Table 1 shows the number of farms and of fields and the total acreage from which information was obtained in each year. In the statistical analysis of yield effects, fewer fields were used than this table indicates, since fields that were sown to a less popular variety such as Hunters or Dreadnought—of which there were not more than 5 in any year—were excluded. Also fields in which parts were treated differently for any one factor were excluded for that factor, but were sometimes used in the estimation of another factor. Hence, the total numbers of fields in different tables do not agree.

The methods of analysis of the yield differences are discussed in the appendix at the end of the paper. Only fields where the information was complete for all factors analysed were included in this analysis.

Christchurch Area

Type of Farming

Mixed arable farming for the production of cereals, pulse crops, potatoes, and pasture seeds, in conjunction with some fat lamb raising, is a feature of the area. However, its proximity to Christchurch has influenced the farming pattern and this is illustrated by the number of

dairy farms producing milk for town supply and the number of horse-training establishments. These have not been included in the survey.

The area falls within the counties of Paparua and Springs, and of their occupied area of 121,000 acres, approximately 9% is devoted to the production of cash crops. Eleven per cent of the total dairy cows in Canterbury are in these two counties.

Fig. 1.—Location of wheat-growing farms in Christchurch survey area.

The farms are seldom large, and most wheat fields in the survey were between 6 and 25 acres. This would also be the size of most fields on these farms. The distribution of the wheat field sizes taken over all five years together was:—

Size of field (acres)	1-2	3-5	6-10	11-15	16-20	21-25
Number of fields	5	23	105	92	81	42
Size of field (acres)	26-30	31-35	over 35			
Number of fields	19	7	6			

Soil types

The soil types on which the farms were located belong to the Waimakariri, Paparua, Templeton, and Springston series, which are soils formed from greywacke alluvium.

Although the area was first chosen because it was considered to be all on one soil type, during the first year of the survey differences between some of the sub-areas became apparent and these were ascribed to the different moisture-retaining capacities. However, a detailed

survey showed that many fields contained parts in two or more of the defined grades of moisture retentivity. Hence no study of the effect of this factor on yield was feasible. A study of the soil maps prepared after a later survey indicates that the fields may be individually more uniform under a different classification scheme. However, it was not then possible to retrace and resurvey the fields for which the wheat-growing data had been recorded some years previously.

Variety

Overall the predominant variety was Cross 7, this being grown in 67% of the fields, the remainder being Fife Tuscan and Solid Straw Tuscan, except for 2% of Hunters or Dreadnought. The relative numbers of crops of the main varieties were similar in all districts except Weedons

TABLE 2. NUMBERS OF CROPS OF THE MAIN VARIETIES (CHRISTCHURCH)

	Year					Total	Per Cent.
	1945	1946	1947	1948	1949		
Cross 7	56	40	48	52	47	243	68
Tuscan	25	24	22	19	21	111	32
Total	81	64	70	71	68	354	

where there were 38 Tuscan crops out of a total of 51. Table 2 shows that there was no trend in the relative popularity of the varieties during the period of the survey.

Date of Sowing

The numbers of crops sown in each month is shown in Table 3 for the five years (during which 68% of all crops were sown in the months of May and June). The autumn weather in 1945 was unfavourable for sowing and there was consequently a large percentage of spring-sown crops. In the last two years of the survey there were no spring-sown crops, and more autumn-sown crops than in the previous

TABLE 3. NUMBERS OF CROPS SOWN IN EACH MONTH (CHRISTCHURCH)

	Year					Total
	1945	1946	1947	1948	1949	
April	—	2	—	—	3	5
May	9	14	26	47	37	134
June	9	27	14	15	19	84
July	10	3	17	5	6	41
August	26	4	8	—		38
September	14	1	2	—		17

two years, although it is doubtful whether the autumn weather was more favourable in those years. This may indicate a trend towards autumn sowings under even less favourable conditions than were formerly required. In the yield analysis for the first three years no significant difference was observed between autumn-sown (before the end of June) and spring-sown crops. However, the errors attached to the estimates of factor effects on yield for the individual years are very high, so that no conclusion of similarity in yields between spring and autumn sowings can be drawn either.

Fertilizer

Almost all crops were sown with 1 cwt or 1¼ cwt of superphosphate per acre, and deviations from this practice did not appear to be related to any other factor or to outstanding yields. The average rate on the 1933 survey was 1 cwt per acre of superphosphate.

Rate of Seeding

The numbers of crops at the various rates were:—

1½	bushels per acre	61 crops.
1¾	„ „ „	100 „
2	„ „ „	87 „
2¼	„ „ „	52 „
2½	„ „ „	18 „
3	„ „ „	3 „

The higher rates of 2½ and 3 bushels per acre were almost exclusively used in the spring sowings, while all the crops at the lowest rate of 1½ bushels per acre were sown in May.

This factor was not analysed for yield effect as it did not appear to exert much influence. Results from experiments have indicated that on the whole, over the average range, rate of seeding does not influence yield.

Grade of Seed

This information was obtained for the year 1949 only, and the numbers of crops in the various grades were:—

Uncertified (or own seed)	68
Certified (grade not specified)	11
Standard	19
Mother	3
Pedigree	7

That is, about two thirds of the crops are sown with uncertified seed, an indication that seed is kept for only two years on the average, after passing out from the certification scheme.

Crop Rotations

When history of the fields for the two years immediately before the wheat crop was considered, most fields belong to one of the ten rotation patterns set out in Table 4. It can be seen that there is no one rotation which is more frequently practised than most others. Its nearness to the markets of Christchurch has influenced the farming pattern of this area, and rotation plans are often adapted to take

TABLE 4. NUMBER OF CROPS IN EACH ROTATION (CHRISTCHURCH)

Rotation pattern	Year					
	1945	1946	1947	1948	1949	Total
1. Grass: grass: wheat	4	6	9	6	4	29
2. Grass: potatoes: wheat	9	6	10	9	8	42
3. Grass: other crops: wheat	4	7	10	9	13	43
4. Cereal: cereal: wheat	1	4	6	4	2	11
5. Any crop: cereal: wheat	7	4		6	4	27
6. Cereal: peas: wheat	7	4	6	4	7	28
7. Any crop: potatoes: wheat	15	9	8	12	5	49
8. Any crop not cereal: peas: wheat	10	4	6	5	5	30
9. Fallow in either year: wheat	6	12	6	9	8	41
10. Any crop: fed-off crop: wheat	12	7	3	5	11	38

TABLE 5. NUMBERS OF CROP IN FIRST OR SECOND YEAR AFTER GRASS

	1945		1946		1947		1948		1949	
	No.	%	No.	%	No.	%	No.	%	No.	%
Crops in first or second year after grass: (Rotations 1, 2, 3)	17	23	19	30	29	45	24	35	25	37
Crops in other rotations	58	77	44	70	35	55	45	65	42	63

TABLE 6. AREA IN WHEAT AFTER GRASS

Year	Acreage of Wheat after Grass	Total Acreage of Wheat	Per cent after Grass
1945	102	1034	10
1946	110	977	11
1947	150	991	15
1948	89	1258	7
1949	66	1182	6
Total:	517	5442	9.5

advantage of special market conditions. It is clear, though, that in no year were many crops sown in the first season after grass. However, there is a tendency for the wheat crop to be taken more frequently in the first or second season after grass in the later years than in the earlier years. This can be seen from the increase in rotations 1, 2, and 3 shown in Table 5. In rotation 3 the "other crop" was mainly peas, sometimes rape, and occasionally chou moellier, linseed or wheat.

The acreage of wheat sown after grass for each year is shown in Table 6, and it can be seen that no marked change has taken place, and the acreages involved are too small to give any measurement of any slight trend.

However the number of fields in which wheat immediately followed peas or potatoes was at least 149 out of 338, i.e., 44%. This figure of 149 is the total of fields in rotations 2, 6, 7, and 8, but it would be slightly higher if the fields in rotations 3 and 9 which followed peas and potatoes were included also.

Analysis of Yield Effects

Because of the small number of fields in each year of this survey, results for the individual years have high errors and thus have little significance. Table 7 shows that the overall mean for the five years was 41.6 bushels per acre but that individual years varied from 35.8

TABLE 7. ESTIMATED YIELD EFFECTS, EXPRESSED AS DEVIATIONS FROM THE MEAN (CHRISTCHURCH)

Factor	Estimated effect in bushels per acre.	No. of crops
General mean	41.6	
Year 1945/46	− 5.8	74
1946/47	4.3	62
1947/48	5.0	62
1948/49	1.7	68
1949/50	− 5.2	65
Varietal difference	0	
Rotations:		
1. Grass: grass: wheat	3.3	29
2. Grass: potatoes: wheat	2.1	45
3. Grass: other crops: wheat	0.8	49
4 & 5. Any crop: cereal: wheat	− 4.1	41
6. Cereal: peas: wheat	− 1.2	24
7. Any crop: potatoes: wheat	− 1.9	45
8. Any crop not cereal: peas: wheat	− 0.3	35
9. Fallow in either year: wheat	0.4	31
10. Any crop: fed-off crop: wheat	0.7	32

to 46.6 bushels per acre. The difference between Cross 7 and Tuscan was zero. These effects are the values of constants fitted on the assumption of an even distribution of numbers throughout sub-classes, with negligible interactions.

The only difference to reach significance was that between the two extreme rotations: 1. grass: grass: wheat. 5. any crop: cereal crop: wheat—in which the mean yields were 44.9 and 37.5 bushels per acre respectively. As this difference was previously known from observation to exist, and its exact measurement was not of great interest, the exact probability level of the significance of the difference was not calculated.

More interest is attached to the comparison in yields between rotations where wheat is grown in the second year after grass and rotations where wheat is grown after two or more years' cropping, that is, rotations 2 and 3 versus rotations 5, 6, 7, and 8. This difference of 2.5 bushels per acre was shown to be significant at the 5% probability, in favour of wheat in the second year after grass.

Cultivations

No standard systems of cultivation seemed to exist so the factor was not analysed for yield effect. Investigation of some selected classes, such as ploughing early versus ploughing late, failed to show any effects on yield.

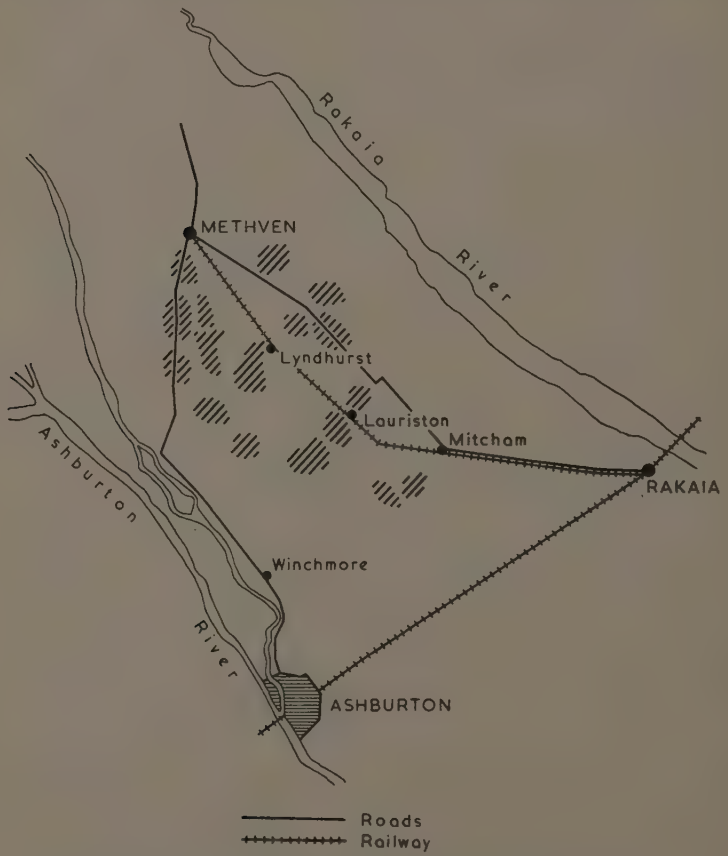

Fig. 2.—Location of wheat-growing farms in Ashburton survey area.

ASHBURTON AREA

Type of Farming

The production of cereals and pasture seed crops, and sheep-farming for the production of fat lambs, form the farming pattern of the surveyed area.

With restricted pasture growth in summer because of a low effective rainfall and again in winter because of cold conditions, the provision of supplementary feed crops is necessary, and considerable areas of rape, root crops, lupins, and oats are grown for the purpose.

Of the Canterbury acreage of wheat, oats, barley, and pasture seeds, the Ashburton County grows about a third, with about the same fraction of the area of supplementary feed crops. This survey does not, of course, cover the whole of the Ashburton County.

The average size of wheat fields was larger in this survey than in the Christchurch survey, as can be seen from the following distribution:—

Size of field (acres)	1-5	6-10	11-15	16-20	21-25	26-30
No. of fields	2	38	73	92	68	72
Size of field (acres)	31-35	36-40	41-45	46-50	51-55	
No. of fields	54	34	14	22	13	
Size of field (acres)	56-60	61+				
No. of fields	21	16				

Soil Types

When the survey was commenced, a special soil survey of the area was made, but with the completion of the Plains and Downlands soil survey, the original work has been superseded.

In the original survey the soils were classed in the Aylesbury and Orari series. The Aylesbury soils in the area comprised the Aylesbury silt loam (A3) which had a depth of soil of more than 18 in. overlying the gravel, and the Aylesbury silt loam (A3S) which had a shallower profile of 9 to 18 in. of soil overlying gravel. The soil type (A3) was found in the Methven, Lyndhurst, and Mitcham districts, and the type (A3S) was found around Lyndhurst, Dromore, and Chertsey. These soil types are now included in the Lyndhurst and Lismore soil series which are described as well drained to droughty soils, from greywacke alluvium and loess, with relatively poor structure.

The Orari soil series were found close to the Rakaia and Ashburton rivers and generally were more fertile soils. There were four divisions: (1) Orari silt loam O3 where the soil was of a greater depth than 18 in. above gravel, (2) Orari stony silt loam O3S where the depth of soil above the gravel was between 9 and 18 in. (3) Orari silt loam overlying a heavy silt loam or clay $O\frac{3}{4}$, (4) the Orari silt loam which overlies what was known as the Dunsandel series $O\frac{3}{4}d$. These Orari soils are now included in the Mayfield series which are greywacke alluvium soils, darker and more moisture-retentive than the Lismore and Lyndhurst series.

Also on a strip approximately two miles in width stretching from Highbank through Barrhill to the Main Trunk railway the Orari silt loam rested on the Aylesbury silt loam and this overlies gravel to a depth greater than 18 in., $\frac{O}{A}3$. This area is now included in the Hatfield series.

To correlate the original and existing classifications the following is the general pattern.

A.3 soils are now mainly in the Lyndhurst series.
A.3S " " " " " " Lismore series.
O.3 " " " " " " Mayfield series.
O.3S " " " " " " Mayfield series.
$\frac{O}{A}3$ " " " " " " Hatfield series.
$O\frac{3}{4}$ " " " " " " Mayfield series.
$O\frac{3}{4}d.$ " " " " " " Mayfield series.

Variety

Over the five years the dominant variety was Cross 7, which was grown in 77% of the fields. Almost all other fields were sown with Tuscan, there being only 1% of other varieties, among which Hilgendorf made its appearance during the last three years of the survey. From 1949 the percentage of Tuscan crops dropped steadily. The Tuscan crops were largely grown on the two soil types A3 and A3S and a marked change-over from Tuscan to Cross 7 on A3S were reflected in the over-all decrease in Tuscan crops. Details of the changes in Tuscan crops as a percentage of all wheat crops on this soil are: —

1947/48	1948/49	1949/50	1950/51	1951/52	Average.
38%	30%	22%	12%	Nil	25%

The distribution of Tuscan crops throughout the soil types for the average of five years is shown in Table 8. In all soils other than A3S, the average over all years fairly represents the percentages of Tuscan in the individual years.

TABLE 8. NUMBER OF TUSCAN CROPS AS A PERCENTAGE OF ALL WHEAT CROPS ON EACH SOIL TYPE (ASHBURTON)

Soil		Soil	
A3	28%	$\frac{O}{A}3$	12%
A3S	25%	$O\frac{3}{4}$	18%
O3	8%	$O\frac{3}{4}d$	9%
O3S	13%	Mixed	16%
	All soils	22%	

Rate of Seeding

The standard rate for crops in the survey was $1\frac{1}{2}$ to 2 bushels per acre, and very few crops were sown at rates outside this range. There was a tendency for the higher rate of 2 bushels to be used on the heavier soil types such as O3, $O\frac{3}{4}$, and $O\frac{3}{4}d$. This factor was not analysed for yield effect.

Date of Sowing

Most crops were sown in autumn, before the end of July in all years except 1947. Yield comparisons of spring and autumn sowing were not made for individual years because of the small numbers of spring-sown crops. The distribution of sowings over the months is shown in Table 9.

TABLE 9. NUMBERS OF CROPS SOWN IN EACH MONTH (ASHBURTON)

	Year					
	1947	1948	1949	1950	1951	Total
April	0	8	2	1	1	12
May	65	86	81	73	52	357
June	27	14	18	15	14	88
July	23	4	4	2	3	36
August	17	1	2	1	6	27
September	5	—	1	4	5	15

Crop Rotations

Over the five years, 37% of the wheat crops were taken as the first crop after grass, and 24% in the rotation "grass, fed-off crop, wheat." This is in contrast to the practice apparent in the Christchurch area where no one rotation was more commonly followed than another. The first rotation was the most common on all soil types except on A3, where the above two rotations occurred equally and on A3S where the second rotation, "grass, fed-off crop, wheat" was the most common and accounted for 48% of the wheat crops. There was no marked change in the frequency of the rotations on any soil type during the period of the survey, and details are shown in Table 10. In the 1933 survey, wheat was the usual first crop after lea in 52% of the cases, and in 36% of cases, rape and turnips was the first crop, wheat following. These percentages are higher than those in the present survey but the earlier survey covered a larger area, and it was noticed then that wheat as first crop after grass was common south of the Rangitata. North of

TABLE 10. NUMBER OF CROPS IN EACH ROTATION BY SOIL TYPE (ASHBURTON)

Rotation	Soil Type							Total
	A3	A3S	O3	O3S	$\frac{O}{A}3$	O$\frac{3}{4}$	O$\frac{3}{4}$d.	
Grass: grass: wheat	29	42	38	12	23	20	14	178
Grass: cereal: wheat	6	5	13	3	6	5	4	42
Grass: peas: wheat	15	1	6	—	7	11	4	44
Grass: fed-off crop: wheat	29	61	11	3	5	5	3	117
Fed-off: fed-off: wheat	13	19	1	—	5	1	2	41
Any crop: peas: wheat	5	—	14	—	5	4	1	29
Any crop: wheat: wheat	5	2	7	3	5	8	4	34
								485

TABLE 11. ESTIMATED YIELD EFFECTS EXPRESSED AS DEVIATIONS FROM MEAN (ASHBURTON)

	bushels per acre					1947–51
	1947	1948	1949	1950	1951	
General mean	33.9	42.7	37.7	41.8	44.7	37.7
Soil type A3	−6.2	2.3	−2.4	−4.5	−4.7	−0.8
A3S	−6.4	−9.7	−14.8	−10.5	−10.5	−8.7
O3	5.2	6.7	7.8	12.8	−2.1	6.0
O3S	−4.6	−1.6	−5.2	5.1	7.2	−2.9
$\frac{O}{A}$ 3	4.2	1.6	1.3	5.2	−0.5	0.3
$O\frac{3}{4}$	2.1	3.8	13.3	0.2	13.0	2.1
$O\frac{3}{4}d$	5.4	—	—	−8.3	−1.2	4.0
Variety Cross 7	2.7	0.7	0.2	2.4	—	1.2
Tuscan	−2.7	−0.7	−0.2	−2.4	—	−1.2
Rotation:						
1. Grass: grass: wheat:	−1.0	−0.7	−0.1	−2.7	5.0	−2.0
2. Grass or fed-off crop: cereal: wheat	5.0	−1.8	−7.2	−4.7	−9.5	−1.2
3. Grass: peas: wheat	2.0	1.4	1.1	5.3	5.2	4.7
4. Grass: fed-off crop: wheat	−0.8	−2.8	4.3	−2.3	1.8	0
5. Fed-off crop: fed-off crop: wheat	2.4	0.8	1.9	0.5	−1.2	−1.7
6. Any crop: peas: wheat		3.0			−1.4	4.3
7. Any crop: wheat: wheat	−7.8	—	—	4.0	—	−4.0
Season of Sowing — Autumn						4.7
Spring						−4.7

the Rangitata the percentage was 40, which agrees almost exactly with the present results, indicating little change in this aspect of the wheat-growing pattern over 20 years.

Analysis of Yield Effects

The factors soil type, rotation history, and variety were included in an analysis for each year and for the five years together. Details of mean effects are shown in Table 11. The greatest yield differences were shown to be due to soil type, in that the Aylesbury series yielded 6 bushels less than the corresponding phases in the Orari series, and the stony phases in each series yielded about 10 bushels less than the non-stony phases. These differences were statistically significant in the five-yearly total analysis. The variation in the yields on each soil type from year to year was high. Differences between soils in any one year were rarely significant. However, the tendency for the Aylesbury series to be well below average and for the Orari series to be above average was consistent throughout.

Although there were insufficient spring-sown crops in any one year to warrant inclusion in the yearly analyses, this factor was analysed over the five years together. There were 64 spring-sown crops out of 464, i.e. 13.8%, and the difference in favour of autumn sowing was 9.4 bushels per acre, which was statistically significant.

Among the rotations, the yield differences in the five-yearly analysis were smaller than several that appeared in the individual years, thus further emphasizing the unreliability of estimates based on relatively small numbers of crops.

The most consistent effect was that of peas, after grass, before wheat. This rotation gave an average significant increase in yield of 4.7 bushels per acre over the mean, for the five years together, and in most individual years was also the highest yielding. In the five years' total analysis it is apparent that the use of peas as a preceding crop, whether after grass or after another crop (rotations 3 and 6), has been the most helpful in increasing yield. The yield difference of 2.0 bushels between the two most common rotations (1 and 4, wheat after grass, and wheat after a fed-off crop after grass) failed to reach significance. This difference was very variable throughout the years.

CONCLUSIONS

The Christchurch survey failed to provide clear evidence of the relative importance of management factors on yield but from the Ashburton survey these may be ranked as follows:—

	Maximum effect in bus. per acre
Soil type	15
Rotational history	9
Spring v. autumn sowing	9
Variety	2

The results of the two surveys, particularly in regard to the effects of different rotational histories, are not consistent, and therefore can provide no basis for generalized conclusions applicable to other wheat-growing areas in Canterbury. Both surveys do however provide information about practices and changes in practices in the two areas.

ACKNOWLEDGEMENT

The field work of these surveys was capably done by the staff of the Economics Section of the Extension Division, Department of Agriculture, Christchurch.

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APPENDIX

Method of Analysis

From the selected panel of farmers, details were obtained for each wheat field on the farm separately. The fields were then treated as independent units, as there was apparently no marked association in yield between fields on the same farm. There was likewise no apparent relationship between size of field and yield, hence areas of fields were disregarded, and all analyses were performed with the variate "yield per acre per field", all fields having equal weight. This gives a biassed estimate of the average yield of the land in the survey district, but this estimate is of less interest than the estimates of the yield effects of the various factors, for which the assumption of equal weight is better. A Least Squares Method of fitting constants was applied to the model.

$$Y_{hijkl} = m + a_h + s_i + t_j + r_k + v_l + \epsilon_{hijkl}$$

where $h = 1 \ldots\ldots 5$ representing years
$i = 1, 2$ spring or autumn sowing
$j = 1 \ldots\ldots 7$ soil type
$k = 1 \ldots\ldots 9$ rotation
$l = 1 \ldots\ldots 3$ variety

with the restricting equations

$$\Sigma a_h = \Sigma s_i = \Sigma t_j = \Sigma r_k = \Sigma v_l = o$$

Not all these constants were fitted in any one analysis, for example in the analysis for an individual year the a_h do not occur and in the Christchurch analysis s_i and t_j do not occur.

This model takes no account of interactions between the factors and assumes that there are none. To have included all the interactions would have made the labour of fitting the constants overwhelming, and it did not seem reasonable to include only a limited number of the interactions. This of course limits the value of the results as the presence of any real large interactions would affect the values of the corresponding constants. This model gives an estimate of the mean such as would be obtained from equal numbers of crops in each of the subclassifications for any factor.

Estimating the Constants

The solution of the normal equations was obtained by the iteration process whereby each constant is in turn estimated from that equation in which it is the diagonal term, using the most recently obtained values of all other constants. Although this method is probably not the most efficient, it is simple, and can be used by relatively untrained computers, and no time is lost in checking and searching for errors. The rate of convergence is very variable and it is not usually easy to forecast this from a simple inspection of the normal equations. For the benefit of others wishing to estimate constants by this method, the number of cycles of the iteration process required for solution to the given accuracy (usually 0.01 bushels per acre) is set out below. This standard of accuracy was required, not for the values of the constants for interpretation, but for the calculation of the standard errors.

Note that the above figures for "Accuracy obtained" refer only to the accuracy of solution of the normal equations, not to the actual values of the constants. The standard errors of the constants were obtained in certain selected cases by solving the normal equations with zeros or 1 in

Analysis		No. of constants estimated	No. of cycles necessary	Accuracy obtained (bus/ac)
Christchurch	5 years	16	6	.001
Ashburton	1948–49	14	11	.01
	1950–51	19	26	.01
	1951–52	17	49	.001
	1947–50	18	11	.001

the right hand side to find the Fisher (1936) constants c_{ii} (really the corresponding diagonal term of the inverse matrix) which were then multiplied by σ^2, the residual variance after removing that due to the fitted constants to give the variance attached to a particular constant. The solution of these equations for c_{ii} usually required about 3 cycles of the iteration process. In testing differences between constants, such as two soil types, the covariance factors c_{ij} (i.e. the non-diagonal terms in the inverse matrix) are required. However, in one case in which the complete inverse matrix was evaluated, these non-diagonal terms were very small relative to the diagonal terms and hence had little effect on the estimate of the variance of the difference between the constants. It is unlikely that there would be a correlation between two effects which are being compared, such as two soil types, and hence all terms of the c_{ij} type were disregarded in the estimates of variance for significance tests of differences. When the standard errors of a few constants had been calculated for any analysis it was usually possible to tell by inspection which of the other constants had any chance of being significantly different from zero (at the 5% probability level), and further testing was done accordingly. The following table shows the standard errors that were calculated.

TABLE OF CALCULATED STANDARD ERRORS

Analysis	Constant	Estimate	Std. Error.	No. of crops in sub-class
Christchurch 5 years	r_1	3.32	2.01	29
	r_2	2.14	1.67	45
	r_6	−1.21	2.22	24
Ashburton 3 years	r_1	0.27	0.98	113
	r_5	−4.48	2.19	21
	t_1	−4.11	1.49	61
	t_2	−11.30	1.51	87
	t_3	6.25	1.54	52
Ashburton 5 years	r_1	−2.00	1.39	172
	r_6	4.33	2.51	24
	t_3	6.03	1.39	81
	t_6	2.13	1.69	53
	v	1.25	0.74	112

Note: r denotes rotation pattern, t denotes soil type, v denotes variety.

It is apparent from these errors that no useful results can be expected from a survey of this type unless relatively large numbers of fields are included. From the above results a tentative minimum of 50 fields could be set for each sub-class for which it is desired that a constant be fitted.

BOOK REVIEW

SILAGE FERMENTATION

By A. J. G. BARNETT

208 pp., Butterworths Scientific Publications, London.

Butterworth & Co. (Australia) Ltd., P.O. Box 472, Wellington, 33/- post free.

There has been such a paucity of text books on fodder conservation since the appearance of S. J. Watson's book in 1939, that this new publication will be welcomed as a useful and timely addition to the literature. The approach is experimental and theoretical, and the book is obviously not intended for the general reader.

The book opens with a brief description of ensilage and of the various practical methods in use to control the process of silage fermentation. A chapter on silos covers all types from the 100-ton stack to the test-tube silo. The discussion on the results obtainable with laboratory equipment is valuable, since it should stimulate the student to active enquiry by his own experiments.

The main theme of the book is concerned with the experimental investigation of the principles underlying ensilage. It covers the problem of losses, the primary lactic acid fermentation, and the secondary fermentations leading to undesirable degradations. Two chapters are devoted to methods of chemical analysis appropriate to silage investigations, considerable attention being paid to chromatographic techniques so useful in this type of work. In the final chapter the nutritive value of silage and the difficult problem of its evaluation by laboratory tests are discussed.

It is obvious from his manner of presentation, that Barnett is unsympathetic toward the empirical approach so common in silage investigation and so apt to yield conflicting results. He holds the view that fundamental relationships underlying the silage problem "will only be found by chemists, biochemists, and microbiologists working with advanced techniques on the same material at the same time". This is, of course, true of most biological problems, but it is an approach which has not been fully exploited in the silage problem.

The student or research worker who undertakes the task of digesting the formidable literature on silage would be well advised to commence by a thorough study of this book. It will be found that the literature has been critically examined, and only those publications relevant to the discussion are included in the bibliography, a feature which should appeal to those who wish to acquaint themselves as quickly and efficiently as possible with the subject of silage fermentation.

R. J. LANCASTER.

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